H.C.M.R
HELLENIC
CENTER
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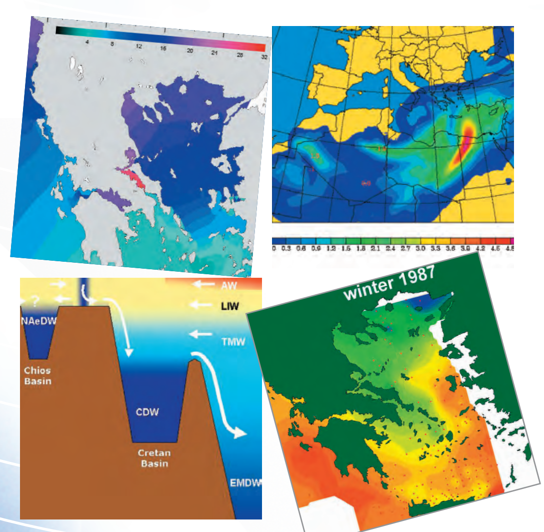
RESEARCH

Editors: E. PAPATHANASSIOU & A. ZENETOS

INSTITUTE OF OCEANOGRAPHY

State of the Hellenic Marine Environment



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Editors: E. Papathanassiou & A. Zenetos

Production consultant: E. Tzovara
Editorial team: A. Zenetos, N. Bellou, S. Kioroglou, A. Zambelis & A. Gouvousi
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List of contributors

Chapter I: Geological Setting
HCMR: Anagnostou Ch., Chronis G., Gogou A., Karageorgis A.P., Lykousis V., Sakellariou D., Papoulia I., Sioulas A. & Tziavos Ch.
IGME: Perissoratis C.

Chapter II: Air - Sea - Land - System
HCMR: Karageorgis A.P., Papadopoulos A., Soukissian T. & Stavrakakis S.
Univ. of Aegean: Tragou E.
Univ.of Kriti: Mihalopoulos N. & Stephanou E.
Univ. of Southampton: Tsimplis M.

Chapter III. Hydrologicy and Circulation
HCMR: Kontoyiannis H., Georgopoulos D. & Petihakis G.
Univ. of Aegean: Tsirtsis G. & Zervakis V.
Univ. of Athens: Lascaratos A. & Sofianos S.
Univ. of Thessaloniki: I. Krestenitis,
Univ. of Southampton: Tsimplis M.

Chapter IV. Chemistry
HCMR: Catsiki V. A., Hatzianestis J., Kaberi H., Krasakopoulou E., Pavlidou A., Psyllidou-Giouranovits R., Souvermezoglou E., Voutsinou-Taliadouri F.& Zeri C.
Univ. of Athens: Dassenakis M.
Univ. of Patras: Varnavas S. P.
NAGREF, Kavala: Sylaios G.

Chapter V. Biota in Water Column
HCMR: Christaki U., Christou E.D., Giannakourou A., Gotsis-Skretas O., Pitta P. & Siokou-Frangou I.
NCSR "Demokritos": Ignatiades L.
Univ. of Thessalia: Kormas K.
Univ. of Patras: Fragopoulu N.

Chapter VI. Biota of the Sea Bed
HCMR: Arvanitidis Ch., Lampadariou N., Panayotidis P., Reizopoulou S., Siakavara A., Simboura N., Tselepides A. & Zenetos A.
NAGREF, Kavala: Orfanidis S.
Univ. of Aegean: Koutsoubas D.
Univ. of Athens: Nicolaidou A., Thessalou-Legaki M., & Legakis A.
Univ. of Kriti: Eleftheriou A.
Univ. of Thessaloniki: Antoniadou Ch., Chintiroglou Ch. & Vafidis D.
Univ. of Thraki: Th. Kevrekidis

Chapter VII. Exploitation of Living Resources
HCMR: Conides A., Papaconstantinou C.
TEI Ipeirou, Igoumenitsa: Kevrekidis K.
University of British Columbia, Canada: Karpouzi V. S.
Univ. of Thessaloniki: Stergiou K. I.

Chapter VIII. Human Activities
HCMR: Anagnostou, Ch., Drakopoulou, P., Corsini-Foka M., Kapsimalis, V., Kontoyiannis Ch., Pagou K., Pancucci-Papadopoulou, M.A, Papadopoulou K.-N., Papathanassiou E., Simboura N., Smith C.J. & Zenetos A.
NAGREF, Kavala: Orfanidis S.
Univ. of Kriti: Karakassis I.
Univ. of Thessaloniki: Stergiou K.I.
TEI Ipeirou, Igoumenitsa: K.Kevrekidis

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INTRODUCTION

This report provides a general assessment of the Hellenic Seas. It was envisaged as a collection of information, providing background comprehensive facts for the broader scientific community and European citizens.

This is the first report of its kind, regarding the Hellenic marine and coastal waters. It is an initiative of the Institute of Oceanography of the Hellenic Centre for Marine Research (HCMR). Research Institutes and Universities across Hellas have joined forces to produce this report. The efforts to coordinate and compile the work, by different institutions, gave very encouraging results

The literature review on all issues examined for the Hellenic Seas with links to climate changes, biodiversity, sustainable development, socio-economic aspects was undertaken using electronic databases and all available sources. All forms of literature were exploited (the most recent information, historical data and the grey literature) and are included in the reference sections at the end of each chapter. In addition, abstracts from conferences have been used where no other relative information was available.

The aim of the report is to offer a common frame of reference, to underline the current state of the marine environment and the related environmental problems, identify the gaps of knowledge and, based on trends, highlight the areas where action is needed.

How to read the report

The report focuses on eight major environmental problems/issues. Homogeneity throughout the chapters was not feasible mainly because of data availability. Issues for which there is lot of data are presented like reviews/reports, whereas issues for which studies are limited are treated like essays based on a few case studies. Each chapter is accompanied by a list of references to the major sources of information.

Chapter I gives the geological setting of the area. It presents a **description** of the Hellenic Seas, gives synoptically the history and mechanisms of their formation and provides some sedimentological details.

Chapter II pertains to **air-sea-land interaction**. The air-sea interaction of the Eastern Mediterranean is examined in three steps: the regional weather and climate systems are described first, followed by wind waves and tides and finally the resulting short and long-term atmospheric fluxes (pollutants and particulate matter) into the sea.

Chapters III and IV describe the **physical and chemical characteristics** and illustrate some short and long term trends in the development of these features Arial distribution of the above parameters is depicted in thematic maps and in compiled tables. Hazardous substances (**heavy metals and PCBs**) are presented in the chemistry section (Chapter IV. Hydrography-chemistry and biology of the water column are addressed separately in coastal and deep seas).

The **biology** section (Chapters V and VI) examines separately the pelagic (microbial, phytoplankton, zooplankton) and the benthic ecosystems/communities. However, in the lagoonal ecosystems both communities are presented together.

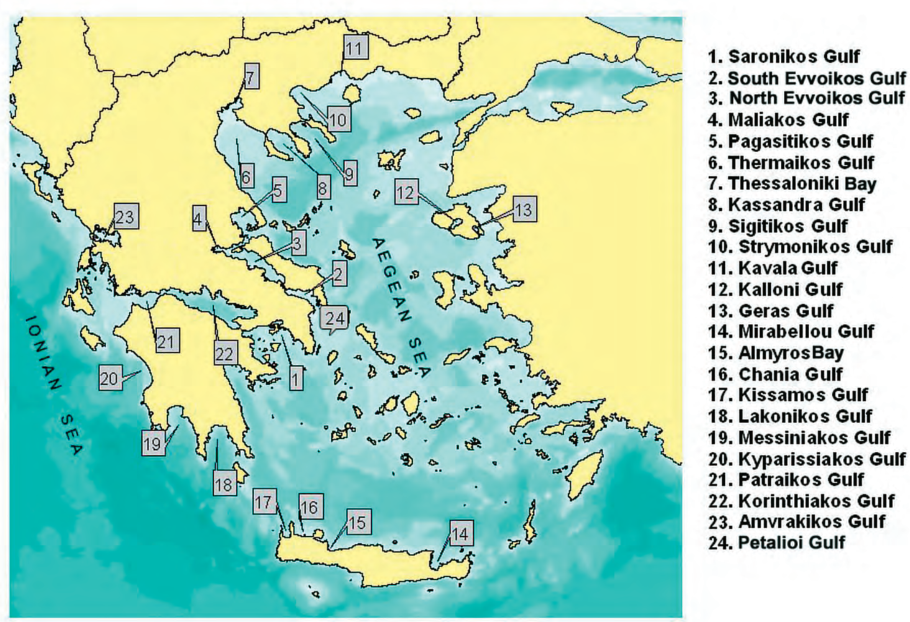
Biological resources (Chapter VII) are treated separately although the impact of fishery/aquaculture activities in the ecosystem is presented under the anthropogenic activities section.

Chapter VIII refers to **anthropogenic stress**. Coasts are treated as fragile natural systems that have economical, social and cultural significance for mankind. Anthropogenic pressures pertain to changes in coastal morphology, hydrology, eutrophication, biodiversity (introduction of Non Indigenous Species), ecological quality status, and ecosystem changes from fisheries and aquaculture.

The editors adopted the rules of ELOT (Hellenic Organisation of Standardisation) for writing-translating the names of localities. (Greece is written as Hellas throughout this volume). Exceptions are the transliteration of Aigaio and Kritikon which are named as Aegean and Cretan Sea, respectively.

A map including the main localities (Gulfs and Bays) addressed in the following chapters is presented below. A detailed map of Lagoons is provided in Figure VI.1 (Chapter VI), while a bathymetric map of the Hellenic Seas and location of major morphological features is presented in Figure I.4 (Chapter I).

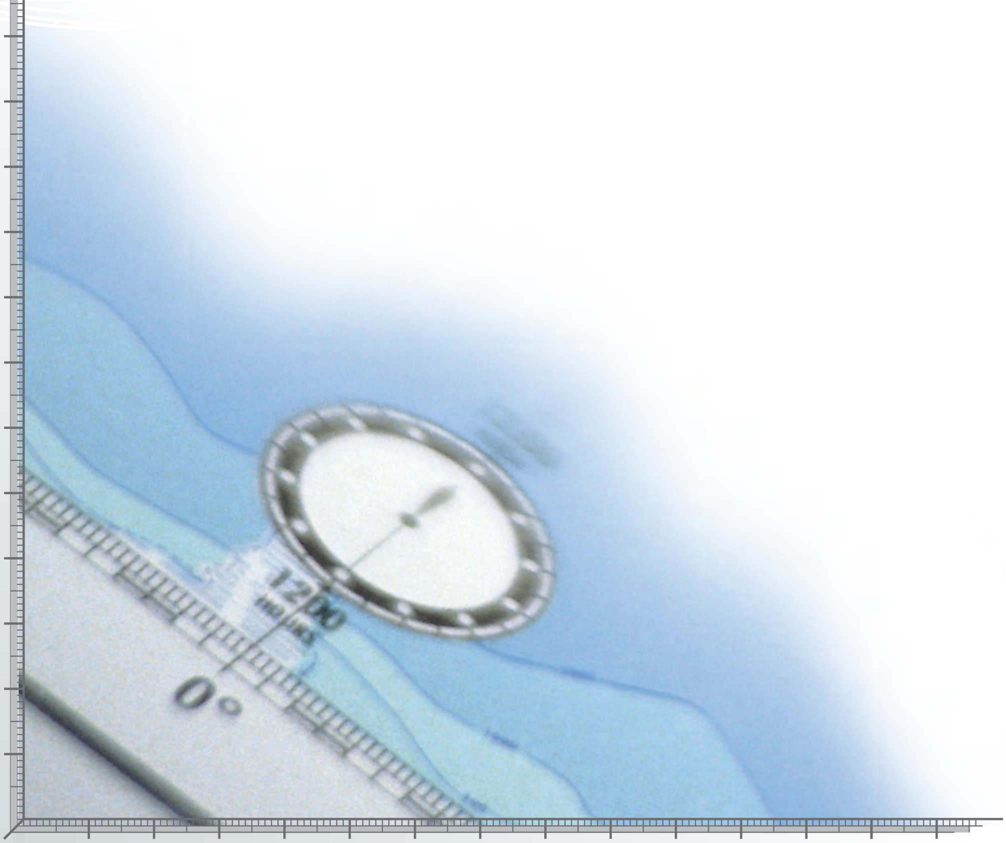
Major Gulfs and Bays



It is believed that the publication of the report provides an important step forward on the coupling of the physics with the chemistry and biology of the region, a precious tool for the protection and sustainable use of our fascinating small ocean, the eastern Mediterranean Sea.

As the Hellenic Seas are probably the only place in the Mediterranean Sea that pristine conditions can be found, we foresee this report also playing the role of a baseline/reference issue so that future publications can make use of all this compiled information and assessment of the Hellenic marine environment.

CHAPTER I
GEOLOGICAL SETTING



I.1. GEOTECTONIC SETTING AND SEISMICITY

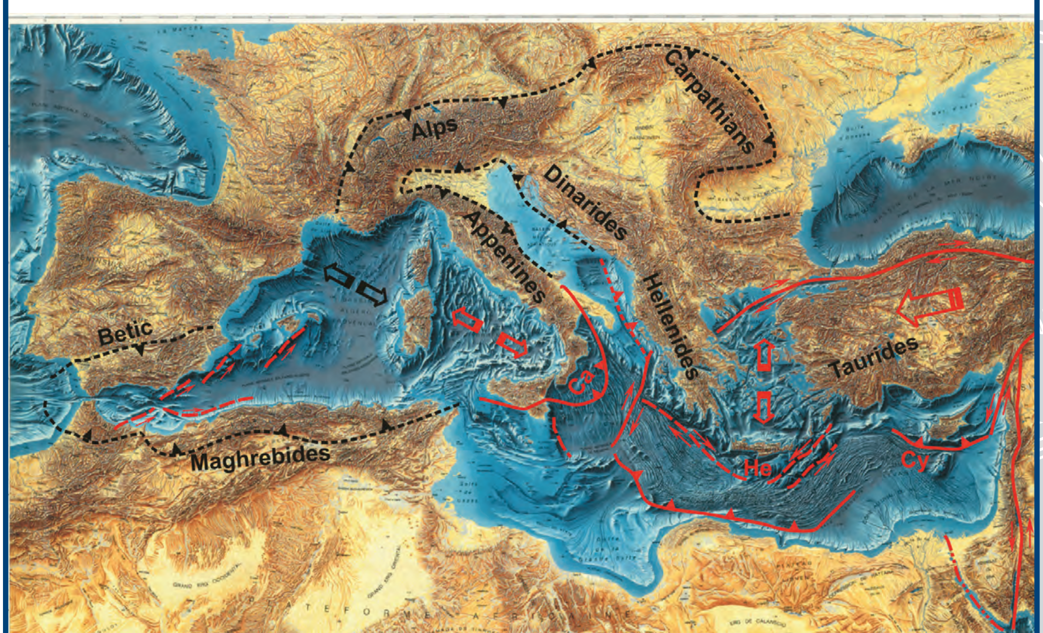
GEODYNAMIC REGIME

The present form of the Mediterranean Sea is the result of continuous interaction of complex geodynamic processes during the last 50-70 million years (Figure I.1) The eastern Mediterranean Basin (Ionian and Levantine) is the only true remnant of the older Tethys Ocean, which is being actually consumed along the active Hellenic, Cypriotic and Calabrian arcs. The East Mediterranean Ridge represents the accrecionary prism formed above the shallow, north-northeastward dipping subduction of the oceanic Mediterranean crust below the Aegean microplate. The rest of the Mediterranean basins, like the Aegean, Tyrrhenian, Liguro-Provencial and Alboran basins, resulted from back-arc extension behind the southwards migrating Hellenic Arc and the east-southeastwards migrating Calabrian Arc.

The present-day shape, topography and bathymetry of the Hellenic region are the result of three main relief-forming geotectonic processes, which were or still are active within the last 10-15 million years:

- the Middle - to Late Miocene post-orogenic extension and exhumation of the alpine mountain belts;
- the migration of the North Anatolian Fault (NAF) westwards into the north Aegean Sea in Late Miocene - Early Pliocene and the westward motion of the Anatolian continental block; and
- the northward subduction of the eastern Mediterranean crust below the Aegean microplate and the resulted stretching of the latter in a north-northeast - south-southwest direction.

The onset of the westward movement of the Anatolian block along the North Anatolian Fault has



Source: *modified from UNESCO/IOC.*

Figure I.1: *Relief map of the Mediterranean region with main geotectonic elements. Red solid and dashed lines with triangles indicate active orogenic fronts (Calabrian, Hellenic, Cypriotic). Black dashed lines with triangles indicate inactive orogenic fronts (Betic, Maghrebides, Alps, Apennines, Carpathians). Solid red arrows mark the sense of movement of strike-slip faults. Thick open arrows mark active (red) or older (black) opening of back-arc basins.*

resulted in the reorganisation of strain in the Aegean microplate. This movement, along with the ongoing collision between the Aegean and the Adriatic microplates in the Ionian region north of the Kefallonia Transform Fault, forced the Aegean microplate to stretch southwards (DEWEY & ŞENGÖR, 1979; JACKSON & McKENZIE, 1988).

Multidisciplinary studies during the last decades have shown that the Aegean microplate undergoes significant extensional deformation in a north-northeast - south-southwest direction. It has been estimated that Kriti Island, the leading edge of the overriding Aegean microplate, is moving south-southwestwards over the subducting eastern Mediterranean crust with a velocity of about 4 cm/yr in respect of the stable Eurasian Continent (JACKSON *et al.*, 1994; LE PICHON & ANGELIER, 1979). Note that the region north of the North Aegean Trough is being considered as part of stable Eurasia. Thus deformation of the Aegean microplate is mainly focused between the North Aegean Trough to the north and the East Mediterranean Ridge to the south (Figure 2). The kinematic situation of the Aegean is characterised by a gradual increase of deformation velocities with respect to Europe, from 10 mm/yr in the North Aegean Trough up to 35-40 mm/yr in the Southern Hellenic Arc (McKENZIE, 1978; LE PICHON & ANGELIER, 1979; JACKSON & McKENZIE, 1988).

Reverse and strike slip faulting dominates along the external Hellenic Arc due to the collision and/or subduction process. Reverse faulting is related to the downward movement of the eastern Mediterranean oceanic lithosphere beneath the

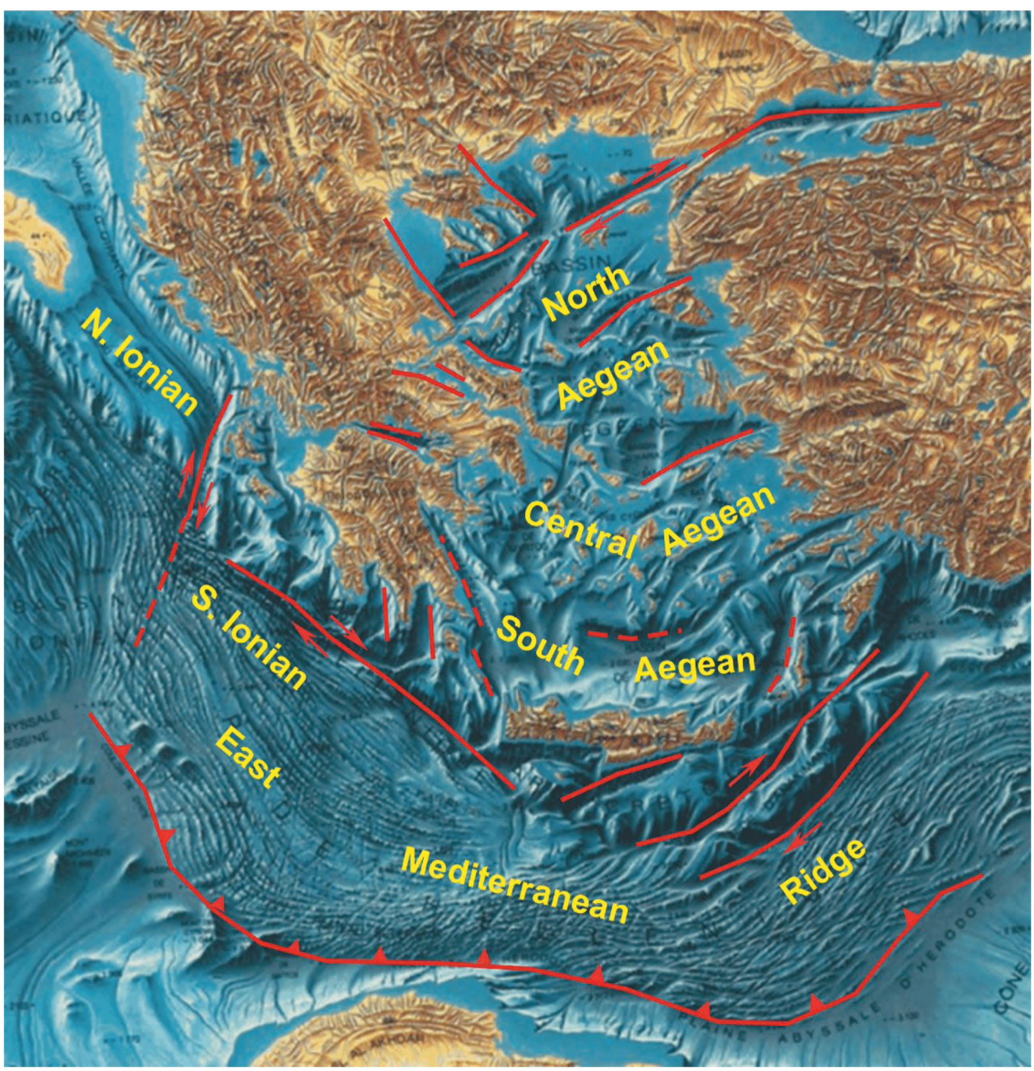


Figure I.2: *Relief map of the Hellenic region with main geotectonic features and names of morphologic domains.*

overriding Aegean microplate and to the collision of the Apoulia with the Aegean continental block off northwest Hellas. Strike slip faulting is closely related to the activity of the Kefallonia transform fault in the Ionian Sea and the arc-parallel transpression and lateral escape of the eastern Mediterranean accretionary prism (LE PICHON & ANGELIER, 1979).

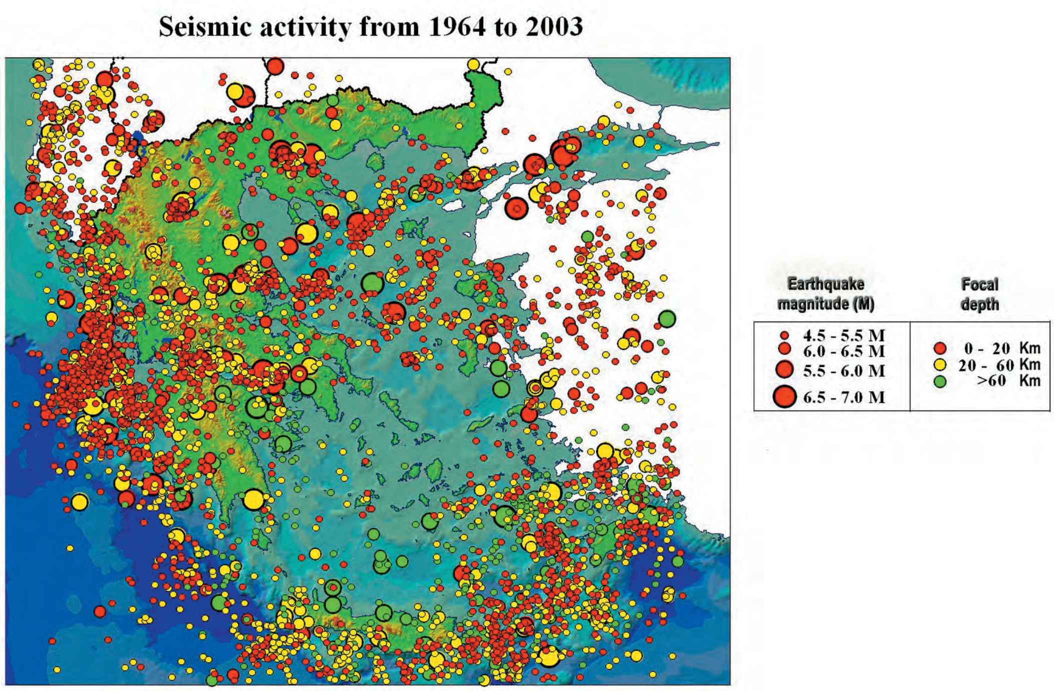
In the back-arc area, normal faulting together with a significant strike slip component, prevails and gives rise to the formation of successive deep basins and structural highs. Many different stress and strain regimes can be distinguished within the deforming Aegean region and are responsible for the high seismicity of specific zones.

Along the North Aegean Trough dextral strike slip faulting occurs as the result of the activity of the North Anatolian Fault's westward prolongation in the Aegean Sea (LYBERIS, 1984; MASCLE & MARTIN, 1990; DINTER & ROYDEN, 1993; GAUTIER *et al.,* 1999).

The distribution of the epicentres of the large shallow shocks ($h < 60$ km) in the Aegean and surrounding area forms several seismic zones (Figure I.3). The external seismic zones form a continuous large seismic belt along the external (convex) side of the Hellenic Arc, and its extension along the western coast of central Hellas, Albania and Yugoslavia. All other zones constitute the internal seismic zones, which have an almost east-west direction (TAYMAZ *et al.,* 1991).

The spatial distribution of the foci of the intermediate focal depth (70 km $\leq h \leq$ 180 km) earthquakes (Figure I.3) is of much interest since the strongest earthquakes (with $M \sim 8.0$) in this region are of intermediate focal depth.

The processes described above over the Hellenic region outline an extremely active geotectonic environment, which gave birth to extensive faulting and resulted in the formation of a fascinating and complicated geomorphology on land and below the sea.



Source: *Data from the geodynamic Institute of NOA.*

Figure I.3: *Earthquake distribution in the Aegean and surrounding area, 1964-2003 M>4.5.*

I.2. GEOMORPHOLOGY AND TECTONIC STRUCTURE

INTRODUCTION

The sea-floor of the Hellenic Seas is characterised by a complex morphology as a result of the geologic history of the eastern Mediterranean and the recent geodynamic processes and movements. The Aegean Sea, between continental Hellas and Asia Minor, has been formed as a back-arc basin behind the southwards migrating orogenic arc and hosts the active volcanic arc. The southernmost Aegean islands (Kythira, Kriti, Karpathos, Rodos) form the southern limit of the Aegean Sea towards the eastern Mediterranean and the Ionian Sea (Figure I.4). The Ionian Sea, located west of continental Hellas and the Hellenic Trench, which surrounds the southernmost Hellenic territories in the south, host the deepest basins of the Mediterranean Sea. Their sea floor relief is strongly controlled by active faulting and is thus very irregular. Most of the gulfs, which dissect the coastline of the Aegean and the Ionian seas are also of tectonic origin.

AEGEAN SEA

The Aegean Sea can be divided into three distinct regions with different morphological characteristics as well as geotectonic regimes: the northern, the central and the southern part.

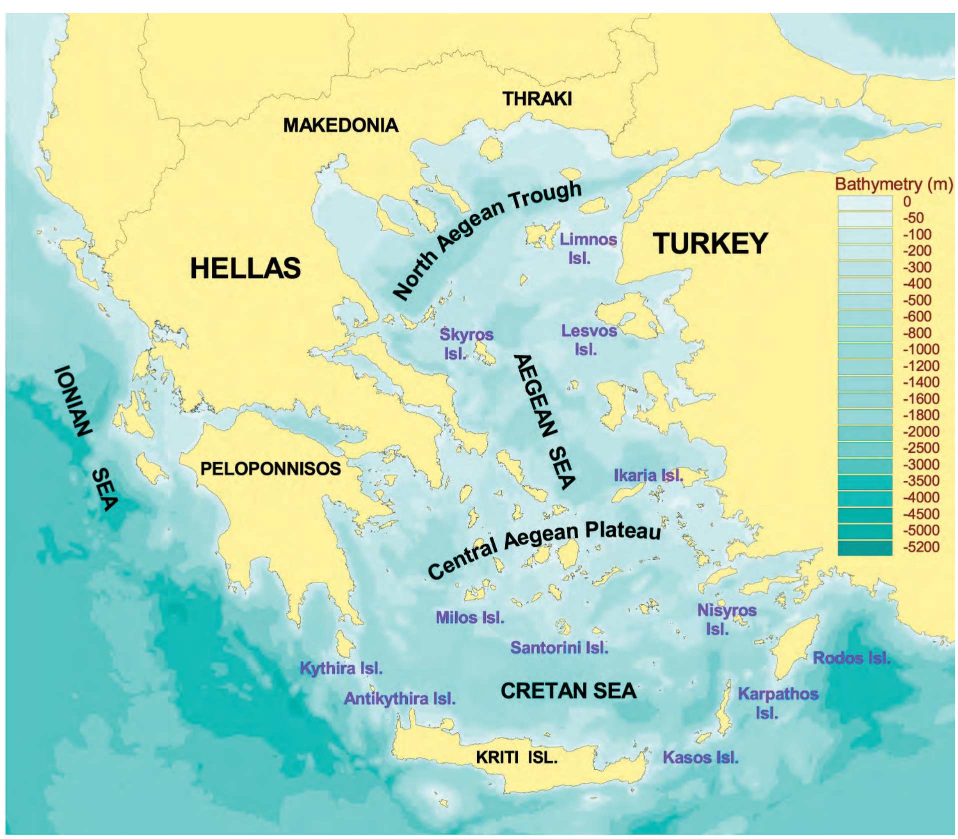


Figure I.4: *Bathymetric map of the Hellenic Seas (depths in meters) and location of major morphological features.*

North Aegean

North Aegean Shelf: The northern margin of the Trough is composed of shallow platforms, which are dissected in NW-SE trending wide gulfs, like the Thermaikos and Strymonikos gulfs. A wide shallow platform, with the Thasos and Samothraki Islands on it, extends between the Strymonikos and Saros gulfs. The North Aegean Shelf represents the offshore continuation of the alluvial planes of northern Hellas and east Thraki. Most of these planes have been formed in Upper Miocene – Lower Pliocene as continental basins filled up by lacustrine and fluvial Plio-Pleistocene deposits (LYBERIS, 1984). They are being drained by large rivers, which feed the shelf and the trough with terrigenous clastic material.

North Aegean Trough: The dominant morphological feature in the Northern Aegean Sea is the homonymous Trough (NAT), which has developed along the trace of the Northern Anatolian Fault (NAF) (Figure I.4) (LYBERIS, 1984). The North Aegean Trough comprises a series of three main elongated depressions, separated from each other by morphological highs (Figure I.5). The eastern depression is a narrow, N70E striking and up to 1 400 m deep basin, which extends from Limnos Island to the Gulf of Saros. The second depression, with an average depth of 1 200 m, is located to the SE of the Chalkidiki Peninsula and indicates a progressive widening and shift of the Trough axis to N50E. The western depression corresponds to the 1 500 m deep and wide Sporades Basin. Sedimentation in the North Aegean Trough comprises mainly of hemipelagic mud, turbidites and gravity driven deposits originated in the outer shelf and upper slopes of the trough.

Sporades-Limnos Plateau (1): The southern slopes of the North Aegean Trough are delineated by steep fault scarps, which represent the sharp contact to the 100-300 m shallow platform extending between the Sporades islands in the west and the Limnos and Imvros islands in the east.

Various basins: Secondary strike slip faults, running parallel to the North Anatolian Fault, together with normal faults, are responsible for the formation of narrow but deep, small basins in the region between the North Aegean Trough and the Central Aegean Plateau (MASCLE & MARTIN, 1990). The 1 000 m ***deep Skopelos Basin (2)***, the 800 m ***deep Kymi Basin (3)***, the 800 m. deep ***S. Skyros Basin (4)***, the 1 000 m deep ***N. Skyros Basin (5)***, the 800 m deep ***Psara Basin (6)*** represent isolated morphological depressions separated from each other by 200-400 m shallow platforms. The 800-1 000 m deep ***Ikaria Basin (7)*** constitutes the southernmost deep basin of the northern Aegean region, before the shallow Central Aegean Plateau. All the above mentioned basins are of tectonic origin, since active faulting controls their subsidence, and they are surrounded by steep slopes.

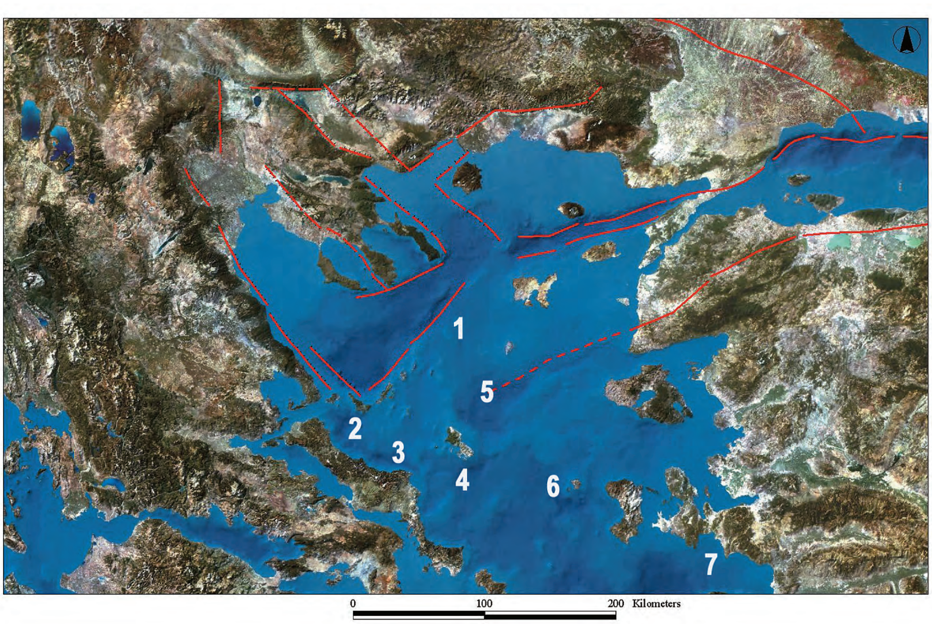


Figure I.5:
Relief map of the north Aegean region, with some of the main, structure forming, active fault-zones drawn in red (1= Sporades-Limnos Plateau, 2: deep Skopelos Basin, 3: deep Kymi Basin, 4: S. Skyros Basin, 5: N. Skyros Basin, 6: Psara Basin, 7: Ikaria Basin).

Central Aegean

The ***Central Aegean Plateau*** (Kyklades Plateau) represents a shallow platform of about 200 m mean depth, which forms the morphological link between the Attiki Peninsula and the S. Evvoia Island to the west and the Menderes region in Asia Minor to the east. The theoretical line, which passes over Andros, Tinos, Mykonos, Ikaria and Samos islands, constitutes the northern limit of the shallow plateau. The southern limit of the Central Aegean Plateau coincides with the Volcanic Arc, to which Nisyros, Santorini, Milos, Poros and Aigina Islands along with smaller islets and submarine volcanic centres belong.

The curved shape of the Central Aegean shallow plateau follows the general shape of the Hellenic Arc and Trench System and is the result of stretching of the Aegean microplate in a NNE-SSW direction (LE PICHON & ANGELIER, 1981; MASCLE & MARTIN, 1990). The gentle submarine morphology of the central Aegean reflects the low seismic potential and the weak neotectonic activity and faulting of the region. Biogenic sedimentation prevails on the shallow platforms between the numerous islands and islets.

South Aegean

A series of deep elongated basins are distributed between the Volcanic Arc to the north and the Island Arc to the south. The south Aegean basins extend from the Argolikos Gulf, off the eastern Peloponnisos, over the Cretan Sea, between Kriti and Santorini Islands, and continue to the Sea of Karpathos, west of Karpathos Island.

The greatest depths of the Aegean Sea are to be found here. The N-S elongated ***Karpathos Basin*** is 2 500 m deep and is bordered by a steep faulted slope towards Karpathos Island. A 1 300 m deep shallow ridge separates the Karpathos Basin from the 2 200 m deep Kamilonisi Basin. The latter is located between the northern coast of eastern Kriti and the Kamilonisi Islet. Next to this and north of central Kriti, the 1 800 m deep ***Irakleio Basin*** occupies the central part of the southern Aegean Sea. Further to the west, a shallower but long and narrow basin follows the shallow ridge, which connects western Kriti with the Antikythira and Kythira Islands and the eastern Peloponnisos.

The formation and distribution of the ***Deep South Aegean basins*** is the result of the geotectonic regime, which was active over the region during the last 5 million years. Nevertheless, the tectonic and seismic activity in the southern Aegean is presently much lower in respect to the northern Aegean. Tectonic activity has migrated southwards and affects the Island Arc with faulting, which is responsible for uplift or subsidence of successive regions along the arc.

The tectonic fragmentation of the Island Arc has resulted in the formation of relatively shallow straits, west and east of Kriti, which allow water exchange between the Aegean Sea and the east Mediterranean.

IONIAN SEA

In the Ionian Sea two different parts may be recognised: the northern and the southern one, with the boundary between them being marked by the Kefallonia strike-slip fault. The northern part can be seen as the southward prolongation of the Adriatic Sea. The northern Ionian Sea is characterised by an extensive shelf, with Kerkyra Island being part of it, connected to a relatively flat basin by a steep slope. The sea-floor morphology changes dramatically in the southern part of the Ionian Sea and coincides with the high seismicity of the region. Normal active faults are responsible for the formation of deep gulfs, like the Messiniakos and Lakonikos gulfs and valleys. The regional tectonics and fault movements are controlling the sedimentation in these areas. Turbidites and gravity driven deposits form the bulk sedimentary infill.

Deeply eroded submarine canyons dissect the shelf and the slope off the Ionian islands and the Peloponnisos and terminate down-slope in small, deep, isolated basins at depths over 4 000 m. Note that the deepest basin ***(Vavilov Deep)*** in the Mediterranean Sea is located in this region, only 30 miles off the SW coast of the Peloponnisos and is over 5 100 m deep.

HELLENIC TRENCH

The succession of the deep basins along the foot of the submarine slope of the Ionian Sea constitutes the western branch of the Hellenic Trough (LE PICHON & ANGELIER, 1979). The trough was considered previously as the boundary between the subducting east Mediterranean oceanic crust and the overriding Aegean continental crust. New data indicate that the segmented trough constitutes the morphological expression of strike-slip faulting between the thinned Aegean continental crust and the accretionary prism of the east Mediterranean Ridge.

The Hellenic Trough continues eastward, south of Kriti and further eastwards, southeast of Karpathos and Rodos islands. The Herodotus, Strabo and Pliny trenches form the central and eastern part of the trough. These trenches have formed along significant strike slip faults, which undertake the lateral escape of the accretionary prism away from the southwards moving thinned Aegean continental crust. The Strabo and Pliny trenches terminate north-eastwards into the Rodos Basin, a 4 000 m deep and relatively young basin within the Levantine Sea.

GULFS

Extensive faulting and vertical tectonic movements have resulted in the fracturing of the Hellenic mountain chains and the creation of deeply incised embayments and semi-enclosed basins (Figure I.6). Recent and active tectonics are the main driving mechanism, which generated and continues to regulate the morphology of Hellas. Intensive faulting resulted in the fragmentation of the upper crust into individual tectonic blocks, which undergo vertical or horizontal movements. These processes resulted in the formation of a complicated geomorphology of the Hellenic peninsula, which shows a mountainous relief with the main direction NW to SE (JACKSON & McKENZIE, 1988; JACKSON *et al.*, 1994). As a consequence, this morphotectonical regime has the formation of a variety of drainage basins and drainage systems, including some very extended drainage areas as well as some smaller ones.

The Thermaikos and Strymonikos gulfs, the two most significant gulfs in the north Aegean, have developed on the northern shelf of the North Aegean Trough basin and receive the waters and fertile material from large rivers, like the Axios and Aliakmon rivers.

The shallow Saronikos and S. Evvoikos gulfs are located at the western edge of the central Aegean Plateau. Mainly biogenic sedimentation prevails on their sea floor.

On the opposite side, the Lakonikos and Messiniakos gulfs constitute two deeply incised, fault-controlled, steep submarine valleys between the three capes of the southern Peloponnisos. They continue down-slope as canyons, which outflow into the deep basins of the Hellenic Trench.

Several semi-enclosed or isolated gulfs occur both along the eastern and the western side of the Hellas mainland. Among them, the Korinthiakos Gulf, with a maximum depth of about 900 m, has

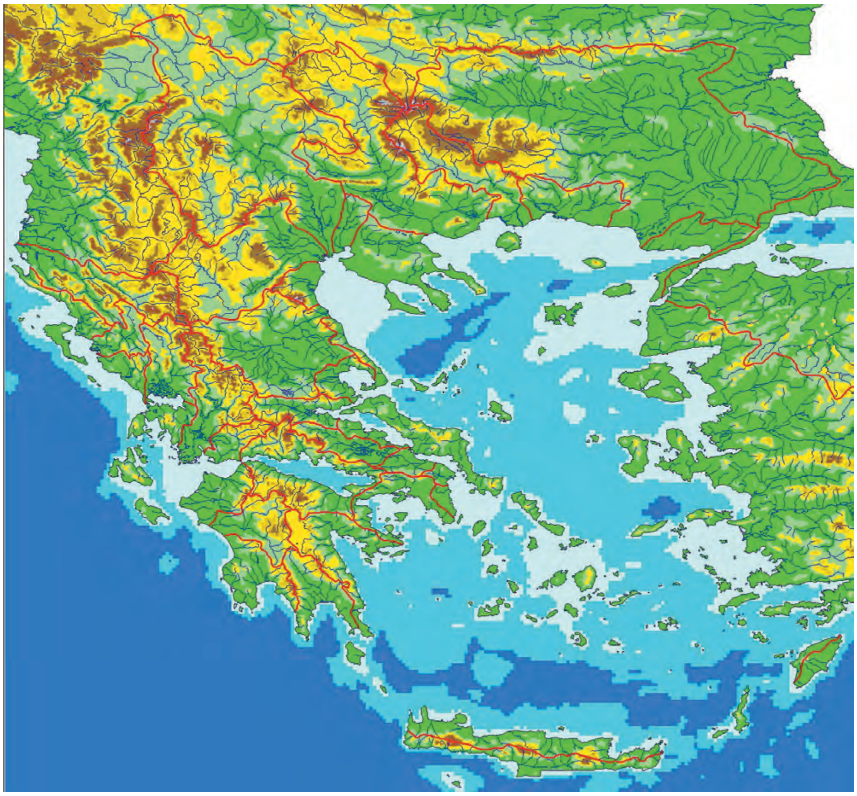


Figure I.6: *The morphology of the Hellenic area. The red line marks the boundaries of the main drainage basins and drainage systems, including some very extended drainage areas as well as some smaller ones.*

developed as a deep rupture between the Peloponnisos to the south and central Hellas to the north (Figure I.7). Together with the N. Evvoikos Gulf they are considered as relatively young and tectonically active basins, formed in the frame of the extensional regime between the SW tip of the North Anatolian Fault and the NE tip of the Kefallonia Fault. The Pagasitikos and Amvrakikos gulfs are shallower semi-enclosed basins on the Aegean and Ionian coasts respectively.

All of the above isolated gulfs communicate with the open Aegean or Ionian Sea through shallow and narrow straits. This peculiar morphology was the main reason for the isolation from the open sea during the last low sea-level stage and their transformation into lakes. The timing of flooding of the former isolated lakes by the sea water was directly related to the depth of the respective shallow straits.

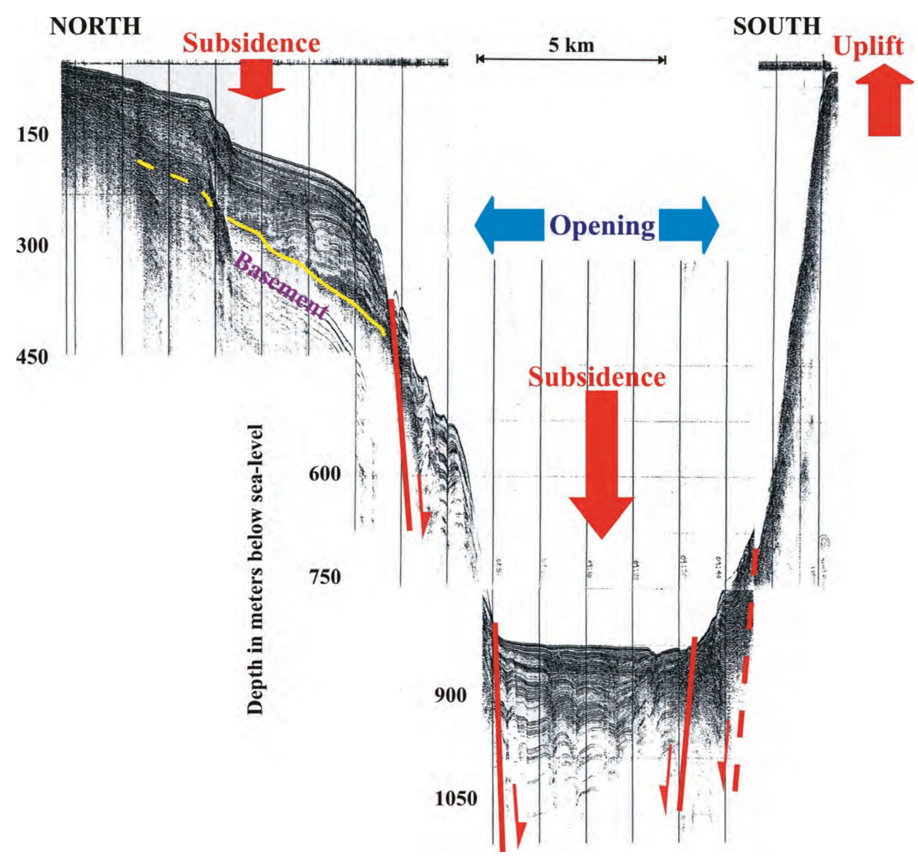


Figure I.7:
Single channel profile from the central Korinthiakos Gulf showing the structure of the basin and the active neotectonic vertical movements, which have led to its formation.

Source: *LYKOUSIS et al., 2005.*

I.3. MORPHODYNAMICS AND CHANGES OF THE COASTLINES OF HELLAS

THE GENERAL FRAMEWORK

Hellas has a coastline of a length of more than 18 000 km. This is an extremely long coastline in comparison with its land area (approx. 130 000 km^2). The coastlines of Hellas show a variety of coastal landforms, such as cliffs and rocky shores, beaches and deltaic coasts.

These coastal landforms have been developed and are constantly changing under the influence of a range of morphogenetic factors, including geology and geodynamics, geomorphology and some climatic factors such as winds which regulate the wave regime and rainfall, controlling the sediment supply to the coasts.

The Hellenic Peninsula and the associated island complexes are parts of the alpine orogeny. The geological structures of Hellas show a dominant NW-SE direction (Figure I.8), which together with the NW-SE / NE-SW faulting system has established the geodynamical regime of Hellas.

The lithology of the Hellenic Peninsula consists of alpidic formations, divided into igneous rocks (acid and basic) ~10%, calcareous rocks ~25-30%, schists ~10-15%, flysch (sandstones, mud rocks, marls) 15% and post-alpidic formations (sands, sandstones, mud and mud rocks, marls, limestones), 35% (Figure I.8).The geodynamical evolution of the Hellenic area led to rapidly alternating coastal landforms (Figure I.9). The majority of the Hellenic coastlines, up to 75-80%, are cliffs and rocky shores. These coastlines consist of hard calcareous rocks and igneous rocks which are relatively resistant to coastal erosion processes. On the other hand, where the cliffs are composed of relatively softer rocks, i.e. schists and flysch, the

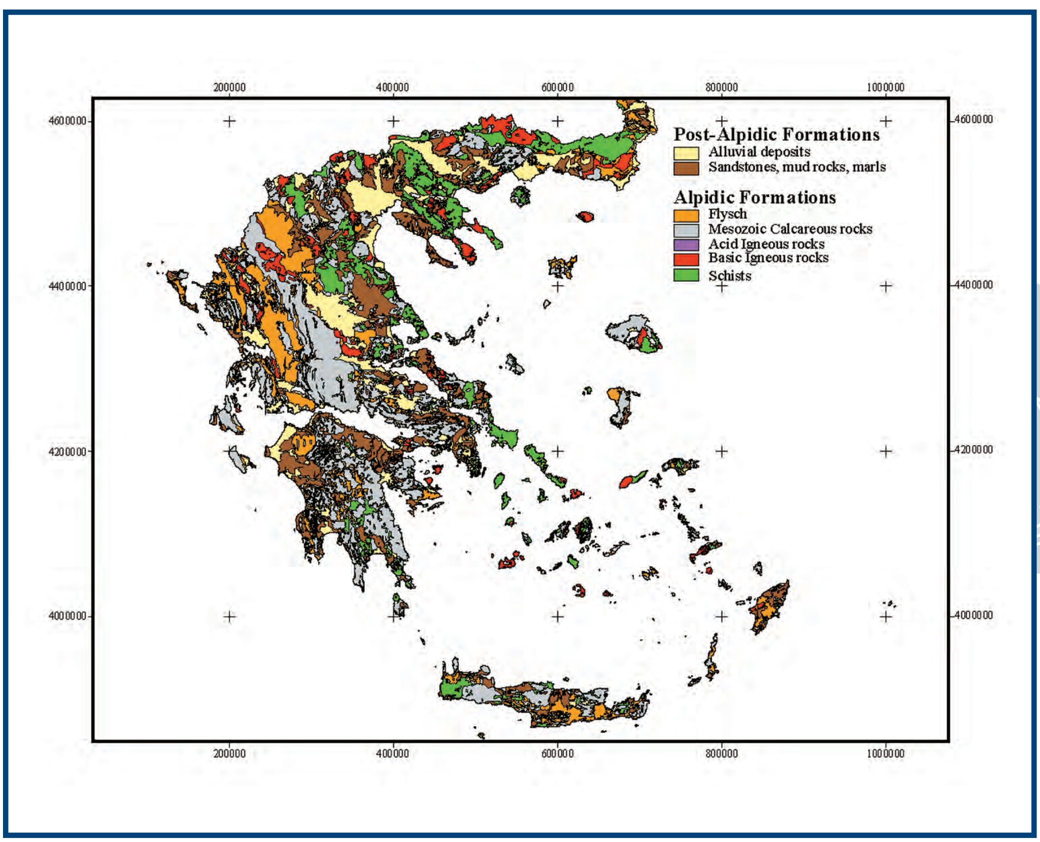


Figure I.8: *The geological structures of Hellas and the main lithological units.*

erosion occurs more rapidly. A portion of ~5% of the coastlines are cliffs with beaches (coastal strips) on the geological substratum of the post-alpidic Plio-Pleistocene (Neogene) formations, which consist of soft sandstones, mudrocks and marls. A significant portion of the coastlines are depositional coasts (~15%), which are formed, where clastic sediments are supplied. These areas are mostly embayments of tectonical origin into which riverine sediments build deltaic coastlines.

The predominant waves that affect the coasts of the Hellenic area are generated by northerly winds, as well as by southerly stormy winds, from the open Mediterranean Sea.

A significant factor for sediment supply is rainfall. Hellas is divided into two zones related to rainfall. Central and western Hellas receives an annual rainfall of more than 1 800 mm/year, whilst in eastern Hellas the rainfall is limited in most areas to less than 600 mm/year. This has resulted in the formation of coastal types with more depositional coasts in the western part than in the eastern part.

In the following, selected examples of different types of the coastlines will be presented.

COASTLINES TYPES

Cliffs and rocky shores

This type of coastline dominates over the whole Hellenic area. Cliffs and rocky shores are found mostly along faulting systems and the cliff morphology is related to the lithology and to the tectonic movements, which are characterised by the uplifting as well as by the subsidence of tectonic blocks.

Cliffs and rocky shores are found (Figure I.9) in the central part of the western coast of Hellas - in the Ionian Sea and some Ionian islands - in the south Peloponnisos, in the northern part of the Korinthiakos Gulf, in the central part of the eastern coasts of Hellas, in some coastlines of Makedonia and in most of the Aegean islands.

A) The simplest cliffs are found where the rocks are decomposed by marine erosion along faults. Some cliffs are high and some are low. The erosion of the cliff face can lead to a shore formation at the base of the cliffs, consisting of rock debris. The faulting system and the lithology, characterised by

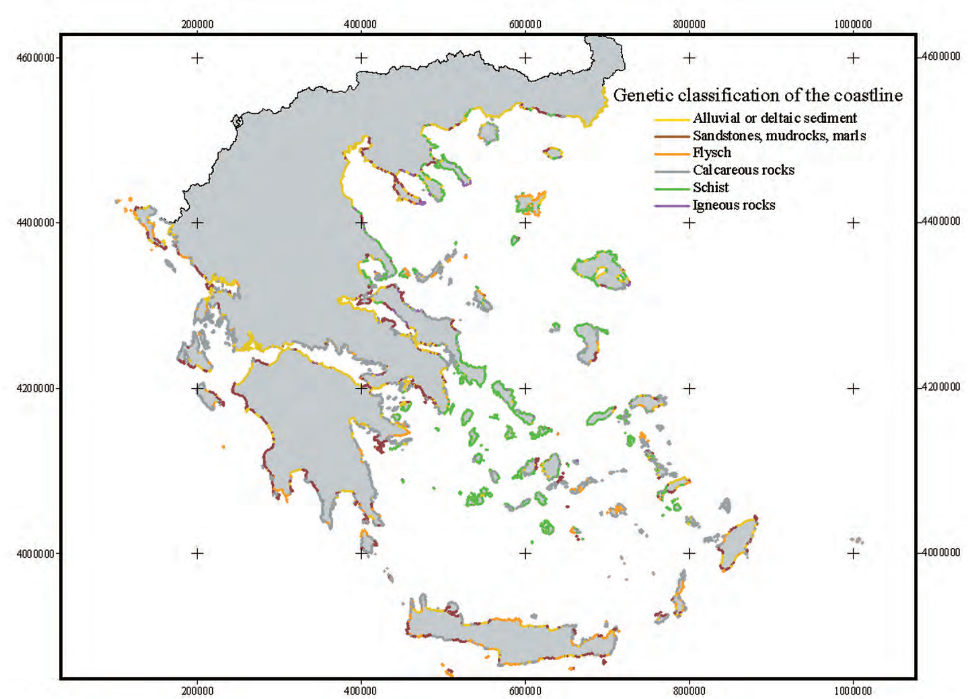


Figure I.9: *The differentiation of the coastlines of Hellas.*

calcareous rocks, are the factors leading to cliff formation of this type (Figure I.10).

B) The northern coasts of the Korinthiakos Gulf (Figure I.11) which is a tectonically very active area and is characterised by an intensive faulting of a NE/SW – W/E system, resulting in many tectonic blocks, which undergo independent vertical movements. Expression of this block fragmentation is the formation of an island array, off the headlands and off the complicated coastline.

The general trend of the tectonic movements is subsidence. Marine notches are formed in the calcareous rocky coasts by physicochemical erosion mainly, but also by biological erosion. These have been registered below the present sea level stand. The tectonic blocks can also tilt. In this cases the notches, which are formed on the calcareous

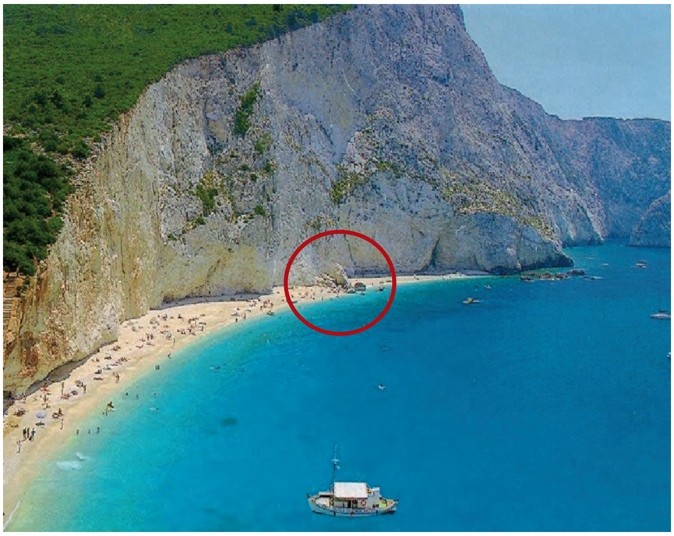


Figure I.10: *Cliffs along faults (photo on the left) and cliffs with a shore formation at the base (photo on the right) from the calcareous rock coasts of the Ionian island of Lefkas. Coastal landslides are remarkable; on the right (marked with a red circle), which are masses of rocks collapsed from the cliff face and accumulated on the shore. These masses are exposed to the erosion activity of the waves.*

Figure I.11: *Cliff coasts in the tectonically block fragmented active area of the northern border of the Korinthiakos Gulf.*

cliff, are uplifted (Figure I.12).

In some very active tectonical areas we have uplifting of the tectonic blocks, which takes place episodically. These processes leave their traces on the rocky coasts by the formation of a series of marine notches. This is the case for the coasts of SE Rodos (Dodekanisos) (Figure I.13).

C) The coasts consisting of calcareous rocks are a very common type of rocky coast in the Hellenic area, which show gentler slopes of the adjacent land morphology (Figure I.14). The general trend of the tectonic vertical movements in those areas is subsidence.

Figure I.12:
Uplifted tectonic blocks on the calcareous cliff coasts of the northern border of the Korinthiakos Gulf (Central Hellas). The formation of recent marine notches is remarkable.

Figure I.13:
A series of marine notches in an episodically uplifted area on the SE Coast of Rodos Island.

Figure I.14:
Rocky coasts in gentler slopes of the land morphology and geological substratum consisting of calcareous rocks.

D) In areas with a lithological substratum of igneous rocks - which are in general tectonically more stable - marine erosion has been acting on these rocks for a long time, decomposing them and creating well-rounded erosive surfaces of the rock blocks and depositing in between them the weathering products, coarser sand consisting of quartz and feldspars (Figure I.15).

E) Some coasts are characterised by shore platforms, which usually can be formed by the intensive wave action. For these formations the term wave-cut platform is preferred. These are 'planation' surfaces that extend from the cliff base to a level below sea level. Erosion and weathering processes shape and modify the shore micro-topography. The most important process for the formation of shore platforms is abrasion, which occurs when waves transport rock fragments (sand, pebbles) across the shore. Waves and rock fragments derived from the erosion are powerful agents of abrasion. In Figure I.16 a shore platform is shown, formed by wave action on an older dune formation on the western coastline of Naxos Island in the Kyklades.

Figure I.15:
Igneous rock shores alternating with sandy pocket beaches filled with erosion products from the weathering of these rocks (western part of Naxos Island – Kyklades).

Figure I.16:
A shore platform formed by wave action on an older dune formation on the western coastline of Naxos Island in the Kyklades.

F) In some cases of abrasion the rock fragments are trapped in the shore platform and they can be transported by the wave action in such a way as to excavate circular potholes. In a shore platform of an older lithificated dune formation on the western coastlines of the Peloponnisos, circular potholes are excavated by wave action, created by NW and SW winds (Figure I.17). The rock fragments, which act in these abrasion and pothole formation processes, are sand grains. The potholes have a diameter of 10 to 50 cm and depths between 10 and 30 cm.

Cliffs with beaches

The coasts of this type are narrow strips of beaches at the base of cliffs on postalpidic Plio-Pleistocene (Neogene) geological formations. These formations are tectonically uplifted relatively soft sedimentary rocks, consisting of sandstones, mudstones and marls, and are undergoing relatively rapid erosion processes. The erosion of these rocks produces sharp cliff faces of different heights (usually from 10-50 m) and erosion products, which form the narrow strips of beaches at the base of the cliffs. This type of coast is relatively common in areas where post alpidic formations occur. Such areas are found on the coastlines of western Hellas, north Peloponnisos, Kriti Island, Rodos Island and the northern part of Hellas. An example of this type of coast is shown in Figure I.18. In this figure the sharp cliff face on the Plio-Pleistocene geological formations is clearly depicted as well as the narrow beach at the base of the cliff face.

Depositional coasts – Deltaic coastlines

We can classify a variety of coastal types as depositional coasts, which have the common characteristic that they may be enlarged by deposition of sediments.

Figure I.17: *Circular pothole formations in a shore platform of an older lithificated dune - western coastlines of Peloponnisos.*

Figure I.18: *Sharp cliff face on the Plio-Pleistocene geological formations and the narrow beach at the base of the cliff face. Coasts from the western coastal region of the Thermaikos Gulf in the NW Aegean Sea.*

Depositional coasts receive sediments from various sources, mainly transported by rivers, either large rivers draining wide catchments and transporting large quantities of sediment, or where the rivers drain steep hinterlands.

Within the group of depositional coasts are the beaches and the dunes associated with them, coastal barriers, lagoons and the most important and continuously changing delta coasts.

These types of coastline are relatively extensive in many areas of the Hellenic Peninsula and the island complexes of the Aegean and Ionian seas.

Beaches and barriers - Dunes

A) Beaches consist of unconsolidated deposits of sand and gravel on the shore and they have different forms. They are long and curved or they form curved pocket beaches between rocky headlands. A very good example of this type of beach is shown in Figure I.19.

B) Coastal barriers are narrow strips of land consisting entirely of sandy material. An excellent example of coastal barriers are those of western Hellas, i.e. the deltaic deposits of the Acheloos River (Figure I.20). The coastal barrier is formed by a dominant longshore transport of the beach

Figure I.19:
An example of a long beach from the SW Peloponnisos.

Figure I.20:
Coastal barriers formed by a dominant longshore transport of the beach sediment and enclosed lagoonal system. Deltaic depositions of the Acheloos River in western Hellas.

sediment from west to east and encloses the lagoon system of Mesolongi.

C) Depositional features closely related to beaches and shaped by similar processes include spits of various kinds. Spits are beaches diverging from the coast and usually ending in landward hooks. An example of a continuously changing spit is the sandy gravel coast off the northern cap of Rodos Island in the Dodekanisos (Figure I.21). The coastline changes its shape during the different seasons of the year, following the predominant direction of longshore drift by waves arriving obliquely at the shore.

D) A special formation associated with beaches is the beach rock. The beach rocks are hard rocks, which occur in beaches originating from the cementation processes of the beach material. Beach sands and beach gravels can be cemented together by the precipitation of carbonates (calcite or aragonite) in the mixing zone, where fresh water mixes with marine salt water. Beach rocks are common in the Hellenic beaches, in Attiki, in the western Peloponnisos and in the Aegean islands (example in Figure I.22).

E) Coastal dunes are generally formed where sand on the shore has been blown and accumulates

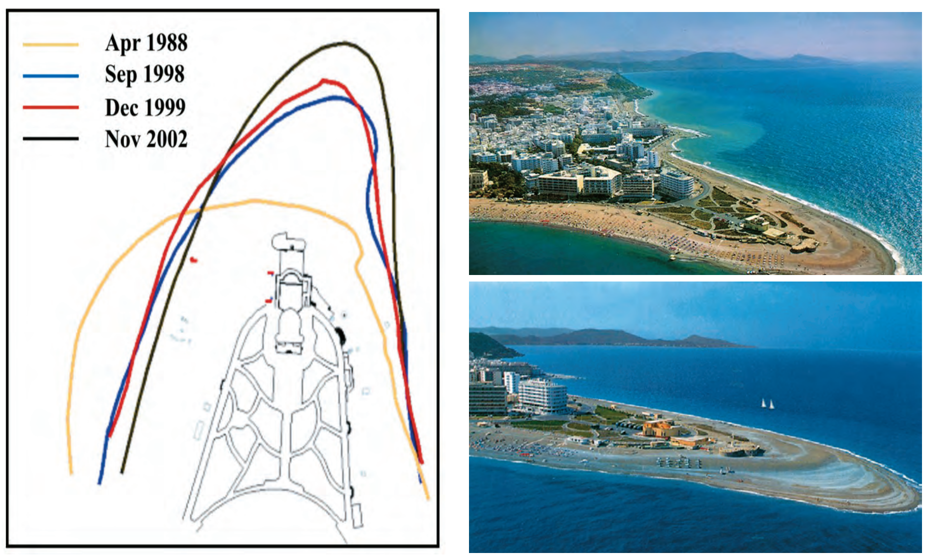


Figure I.21:
The morphological changes of the coasts from the winter state to the summer state. In winter the S-SE winds predominate leading to the formation of a sand spit facing to the west and in the summer the NW-W winds predominate, which totally change the shape of the spit and create a new one facing to the east. The map shows the changes of the coastlines in different seasons of the year. The photos on the right show the summer and the winter formations.

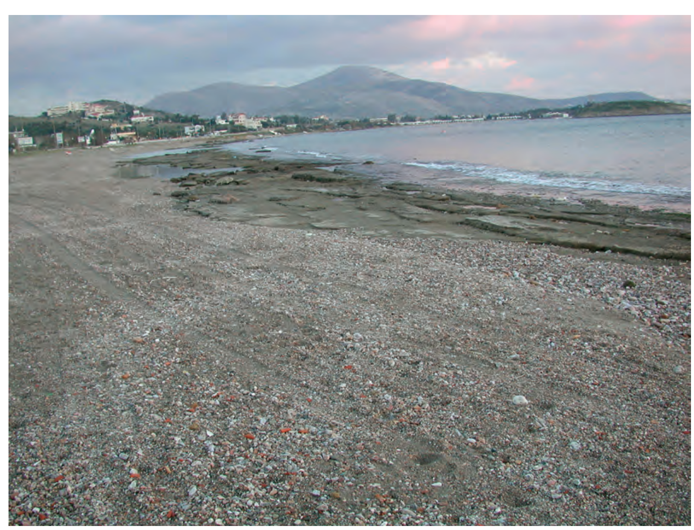


Figure I.22:
Beach rock formation on the Saronikos Gulf coast, near Lagonisi, Attiki.

at the back of the beach. Their growth and shape are related to a source of sand that can be moved by the wind, to wind flow characteristics, rates of eolian transport and patterns of erosion and deposition. In Hellas, coastal dunes are formed in many places (examples in Figure I. 23).

Lagoons

Coastal lagoons are areas of relatively shallow water that have been separated from the sea by the deposit of sand barriers. Many lagoons are formed along the Hellenic coastlines. The most important lagoon complexes are in the Amvrakikos Gulf and Mesolongi-Aitolikon area. Additionally, we can name the Lefkas lagoon in the northern part of the Ionian island of Lefkas, the Araxos lagoon in the northwest part of the Peloponnisos, the Kaiafa Lagoon in the western part of the Peloponnisos, the Gialova Lagoon in Navarino Bay, southwest Peloponnisos. The size of these lagoons is a few square kilometres.

Simple and temporary lagoonal formations are found where the mouth of the river can be enclosed by a wave-built barrier. In Figure I.24 a temporary lagoonal formation at the Aisonas (Mavroneri) river mouth on the western Thermaikos coast (NW Aegean Sea) is shown. This type of lagoon is formed when river floods discharge sediment after heavy rain. The temporary lagoon of the Aisonas River was formed after the very intensive rainfall of December 2002. The wave action progressively rebuilt this lagoon after the return of normal weather conditions.

Another type of lagoon is the long and narrow shaped lagoon, which extends parallel to the coast, separated from the sea by barriers. One example is the Kaiafa Lagoon in the western Peloponnisos.

In some cases the geological substratum acts as a headland and regulates the sand barriers of the lagoon and the lagoon's configuration. The best example of Hellenic coastal lagoons of this type is

Figure I.23: *Coastal dunes on a beach of the Kyklades Island of Naxos, with a height of approx. ~1,5 to 2 m (left) and of the western Peloponnisos, where the height of some coastal dunes reaches 7-8 meters and are covered with a variety of vegetation (right).*

Figure I.24: *Temporary lagoonal formations of the Aisonas (Mavroneri) River mouth on the western Thermaikos coast (NW Aegean Sea). These formations build a suitable breeding/ resting place for birds (photo on the right).*

the lagoon of Lefkas in the northern part of Lefkas Island in the Ionian Sea (Figure I. 25).

Deltas

Delta is a term used to define geomorphologically the depositional lowlands formed around river mouths. The rivers deliver an abundant water and sediment yield to the coast, which depends on the geology and geomorphology of the drainage basin as well as the climate, controlling the weathering of the rocks and the erosion and transport of the weathering products.

The size and shape of the Hellenic deltas depend mainly on two factors:

- the rate of rivers sediment yield, and
- the effects of waves on the accumulating sediments.

In the Hellenic area the tide fluctuations are relatively small diminishing the role of tides in building delta types.

Using these two factors we can classify the Hellenic deltas into various types.

- By relatively stark fluvial supply and low wave energy a branching digitate outline can be formed. A good example of this delta type is the Axios delta, in the Thermaikos Gulf (NW Aegean Sea) (Figure I.26).
- When wave action is somewhat stronger the deltas develop smoother, cuspate outlines.

Figure I.25: *The lagoon in the northern part of Lefkas Island in the Ionian sea, where the geological substratum acts as a headland and regulates the sand barriers and the lagoon's configuration (aerial photo on the left, land photo on the right).*

Figure I. 26: *The branching outline delta type formed by relatively stark fluvial supply and low wave energy (Axios delta in the Thermaikos Gulf - NW Aegean Sea).*

The Acheloos delta, in western Hellas (Figure I.27) is formed by large quantities of sediments, which have been delivered to the river mouth. The enlargement of the delta front is relatively rapid but no branching digitate outlines are formed. The wave action shapes the deposited material into cuspate outlines, sorting the delivered material to form sandy beaches and trailing spits.

- With stronger incident wave action, delta outlines become lobate. This is the delta type of the Nestos River in the north Aegean Sea.
- When stronger open sea waves reach the coasts the delta blunts. The sediment delivered to the river mouth is quickly dispersed by the waves. Deltas are poorly developed on high wave energy coasts. This is the delta type of the Pineios River flowing out into the northwest Aegean Sea (Figure I.28).

The deltaic plain of the Acherontas River in NW Hellas shows morphological features consisting of an alteration of older river beds and river banks into bow-shaped field forms. These curved

Figure I. 27:
The Acheloos delta in western Hellas. Delta material shaped into cuspate outlines sorting the delivered material to form sandy beaches and trailing spits.

Figure I.28:
The Pineios delta in NW Aegean Sea.

morphological features are formed concentrically, following the same orientation as the present bow-shaped beach (Figure I.29).

Studying the mechanism of the present beach morphodynamic we found important results. We combined these results with observations on the morphology of the deltaic plain and we propose an explanation of the mechanisms of the formation of these morphological features.

On the one hand, we have the curved morphological micro-crests which are older, long and narrow spits, migrated alongshore as a result of the diffractory dynamics of the waves and, on the other hand, we have the river bed beside them. By intensive river flow the long spits can be cut at the river mouth (in the south), starting a new procedure for the formation of a new long and narrow spit. This procedure took place many times in the last 5 000 years, since the stabilisation of the sea level at the present state and results in the formation of the land into bow-shaped narrow strips of micro-crests and micro-depressions (the older river beds).

Deltas are depositional formations, which change continuously with time. Stages in the evolution of deltas can be registered and traced. An example of coastline changes during the last 2 500 years is shown in Figure I.30 in the Thermaikos Gulf in the NW Aegean Sea.

On the left we can see the drainage basins of several large rivers that flow into the embayment to the north. The large load of sediments carried by these rivers has resulted in filling-in hundreds of square kilometres of the former Thermaikos Gulf. On the right we can see the different stages of this filling-in procedure and the resulting coastal changes.

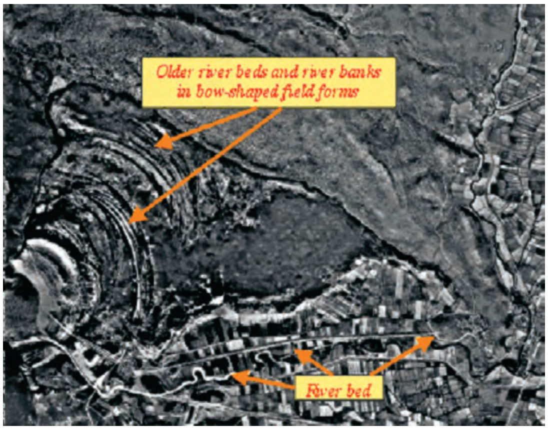


Figure I.29:
The deltaic plain of the Acherontas River in NW Hellas shows morphological features consisting of an alteration of concentrically older river beds and river banks into bow-shaped field forms (explanation in text).

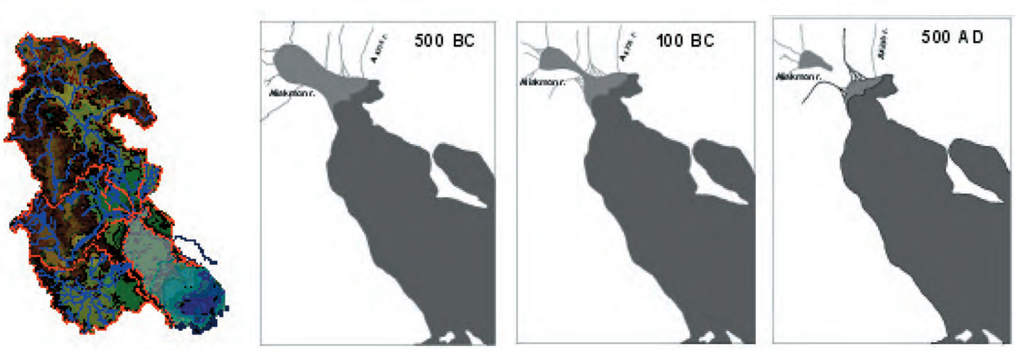


Figure I.30:
Coastline changes and evolution in the last 2 500 years in the Thermaikos Gulf in the NW Aegean Sea.

CONCLUSIONS

Studying the coastlines, which are the active boundaries between lithosphere, hydrosphere and atmosphere, we can discover how essential the nature of coasts is and how it is determined by large scale changes of the earth's system e.g. geological and geodynamic processes, which extend in space and time as well as by more local and rapid changes e.g. weather conditions, waves, etc.

These processes in coastal areas produce changes that extend from a few meters to many kilometers and that can occur in a few seconds, hours, or days. These processes mark the large or the small scales in space and time and this leads to the integrated approach of the study of coastlines.

This approach describes the central philosophy used for the study of Hellenic coastlines.

The coastlines of Hellas are totally dominated by the characteristic tectonism of the Hellenic Peninsula and are classified as follows:

- cliffs and rocky shores of Mesozoic hard calcareous and igneous rocks, as well as of relatively softer rocks i.e. schists and flysch, (~80%),
- cliffs created by relatively rapid erosion of the postalpidic Plio-Pleistocene (Neogene) geological formations consisting of relatively soft rocks (sandstones, siltstones and marls) with narrow beaches at the base of the cliffs, (~5%) and
- depositional coasts, created by the dynamics of the rivers, which have played a large role in carrying sediments from the eroded highlands into the morphological embayments to form large coastal plains, with shores, varying from pebbly or sandy beaches to muddy-marshy shorelines, (~15%).

A few examples of these coastal types are given in this contribution. The coastlines of the Hellenic Peninsula and the island complexes show a variety of types and a rapidly changing alternation from one to another type of coast.

I.4. CHARACTERISTICS OF SURFACE SEDIMENTS

PROPERTIES OF SURFACE SEDIMENTS

The sea floor is virtually covered by unconsolidated sediments formed by a wide variety of substances from many sources. The constituents of marine sediments may be considered under six headings (SVERDRUP *et al.*, 1942): (1) detrital material, largely of immediate terrigenous origin (Figure I. 31a, b), (2) skeletal remains of organisms and organic matter (Figure I. 31c), (3) products of sub-aerial and submarine volcanism, (4) inorganic precipitates from sea water, (5) products of chemical transformation taking place in the sea, and (6) extraterrestrial materials. The first two categories represent the major sediment constituents worldwide, whereas the other four are only recorded in certain regions of the world's ocean.

One of the fundamental mass properties of sediments is texture. An accurate knowledge of the particle-size distribution provides useful background information for a variety of marine scientists, e.g. biologists, chemists, geologists and physicists, each one of them using grain-size properties to address different problems. In addition, one of the most important chemical constituents of marine sediments is calcium carbonate, a predominant component of skeletal remains of plants and animals; calcium carbonate in marine sediments also originates from the erosion of inland and coastal carbonate rocks. Factors which determine the accumulation and deposition of calcium carbonate need to be investigated, in order to contribute to a better knowledge of a wide range of issues, such as the global carbon budget or the formation of limestone. Thus, the study of grain-size and carbonate content of marine sediments constitutes a sound basis for describing the general characteristics of the sediments.

Our knowledge regarding the characteristics of the Hellenic Seas' sediments is based on numerous small-scale investigations conducted over the past 20-30 years by national or multinational scientific groups, which focused primarily on coastal research. Large-scale surveys have been carried out by Russian scientists in the 1970s but covered only international waters and the number of samples collected in the Aegean Sea was limited (EMELYANOV & SHIMKUS, 1986). The Ionian Sea has not been studied in detail and available information is sporadic, dealing mainly with nearshore areas.

The main objective of the present contribution is to present a synthesis of previously published and unpublished surface sediment grain-size and carbonate content data. Their distribution patterns will be presented, discussed and interpreted in relation to (1) the sources, (2) the general circulation, (3) the bathymetry, and (4) the latest sea-level rise.

DATA USED FOR THE PRESENT ASSESSMENT AND METHODOLOGY BEHIND THEM

A great number of surface sediment samples have been collected over past decades from the Hellenic Seas. Sampling equipment used were standard Van-Veen and Reineck grabs, and box-corers (Figure I. 31d). Two of the most active oceanographic scientific groups in Hellas have been the Hellenic Centre for Marine Research (HCMR) and the Institute for Geology and Mineral Exploration (IGME). For the purposes of this work data holdings of the two centres were merged into a common data base (Ocean Data View; SCHLITZER, 2003), containing latitude (˚N), longitude (˚E), station name, sand (%), silt (%), clay (%), and carbonate content (%) data. The total number of records was 2 878 for grain-size data and 1 779 for carbonate content (Figure I.32). Analytical procedures were based on the methodology proposed by FOLK (1974). Basically, sand fraction was separated by wet sieving and the fine silt and clay fractions were analysed by the pipette method or a Sedigraph (Micromeritics 5100) analyser (Figure I.33 a). Carbonate content was determined by various methods, i.e. combustion, the carbonate bomb, or by a CHN analyser (Fisons Instruments; Figure I.33.b).

Depending on their texture, marine sediments can be subdivided according to various classification schemes and nomenclatures. The classification scheme of FOLK (1974) uses the proportions of gravel (material coarser than 2 mm), sand (material between 0.063 and 2 mm), and mud (material finer than 0.063 mm, i.e. silt plus clay) to

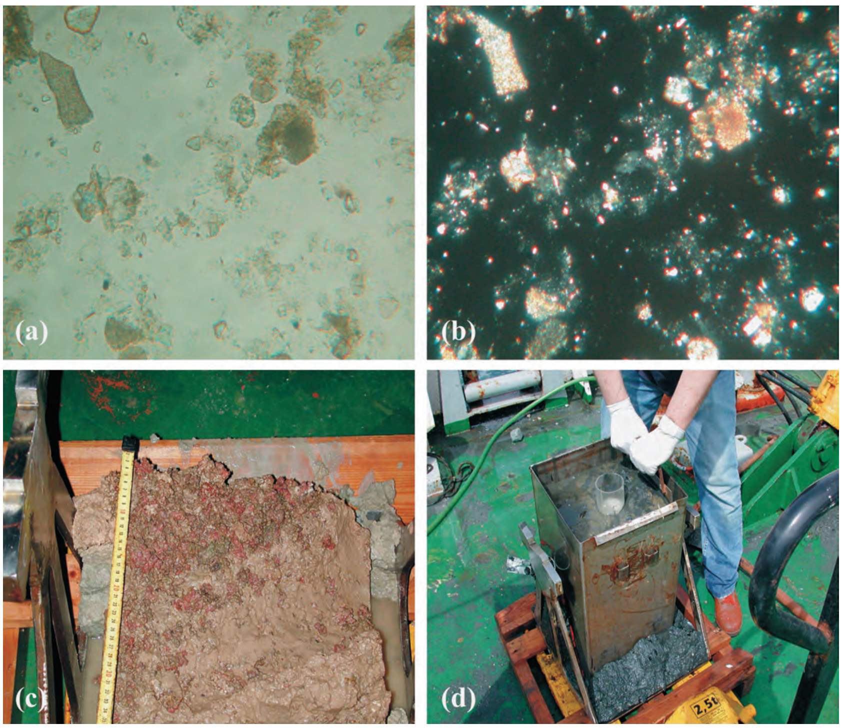


Figure I.31:
a: *View of sediment grains (smear slide) under the microscope (normal light) with minerals and biogenic debris,* ***b:*** *same sample under polarised light,* ***c:*** *sea floor surface sediment from the Ionian Sea showing the abundance of biogenic shells and debris (red-coloured algae), and* ***d:*** *box-core sample from the Saronikos Gulf. A short length (60 cm) tube is inserted in the sediment in order to obtain a vertical profile of the sub-bottom beds (core).*

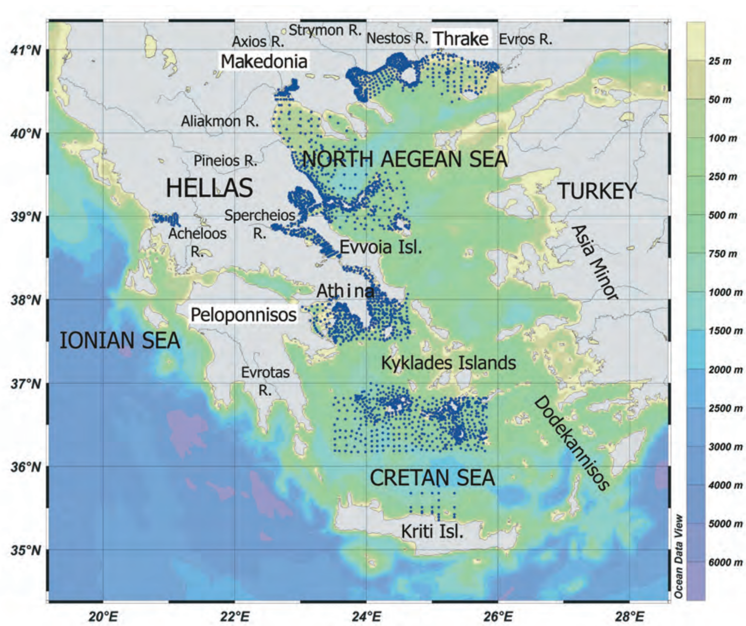


Figure I.32:
Locations of surface sediment sampling stations (blue dots).

place sediments in one of fifteen major groups. In the present work we use the variation of the aforementioned classification scheme adopted for muds, which depends on the relative proportions of sand, silt and clay; this scheme distinguishes ten major textural classes.

North Aegean Sea

Sediments collected from the north Aegean Sea were recovered from the Thessaloniki Gulf, the Thermaikos Gulf, the Sporades Basin, the area between the North Sporades Islands and Skyros Island, and the north Aegean continental shelf and upper slope (water depth <250 m). Sand and silt are the major constituents of the sediments, with a minor amount of clay and, therefore, these sediments are classified as sands, muddy sands, muds and silts (Figure I.34). Sand is the predominant sediment fraction in the continental shelf and upper slope of the north Aegean Sea, which extends eastwards from Chalkidiki and up

Figure I.33: ***a:*** *Micromeritics-Sedigraph grain-size analyser of the mud fraction equipped with automatic sample changer,* ***b:*** *Fisons instruments CHN analyser used for the determination of organic and inorganic carbon, hydrogen and nitrogen.*

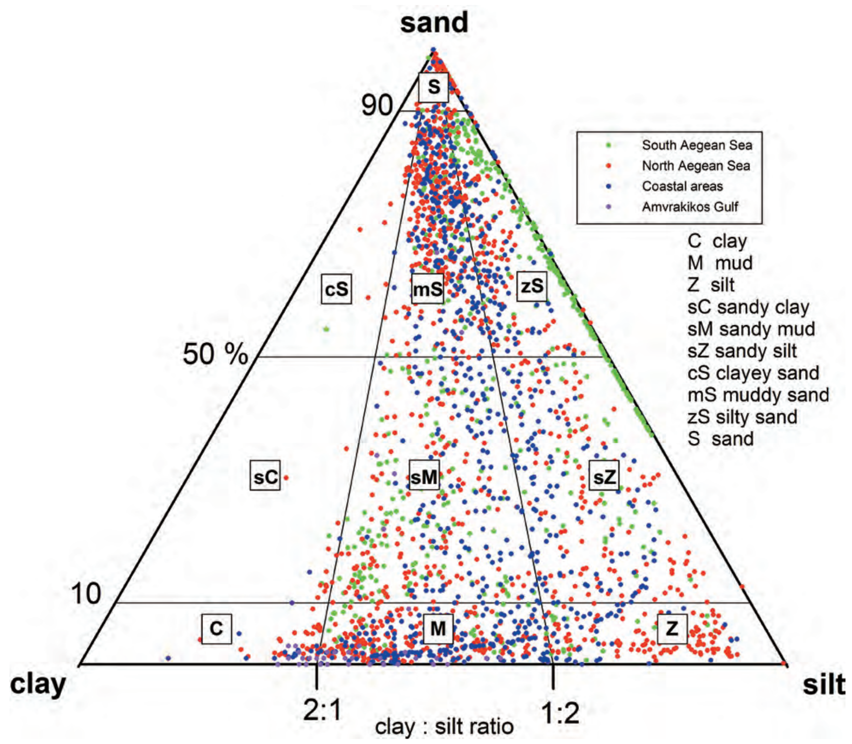


Figure I.34: *Sand-silt-clay ternary diagram of surface sediments from the Hellenic Seas.*

to the Evros River mouth (Figure I.35). Sand contents are generally >40% and in some areas, e.g. offshore the Evros River mouth and around Samothraki Island, sand increases to >90%. Accordingly, silt and clay contents are generally low, except for (1) the Strymonikos Gulf, (2) near the Nestos River mouth, and (3) near the Evros River mouth, where silt values are >40% and clay values >30% (Figures I.36, I.37).

The sea bed of the Thessaloniki Gulf is characterised by muddy sediments, with sand content <20%, silt content in the range of 30-50% and clay content in the range of 40-60% (Figures I.32-I.34). Higher amounts of sand (>60%) are observed in the central and eastern sector of the Thermaikos Gulf. In the western sector of the gulf, where the rivers Axios, Aliakmon, Loudias and Pineios discharge, silt and clay fractions predominate. Sediments of the Sporades Basin are mainly muds, with sand content <20%, silt content in the range of 30-70% and clay content in the range of 30-70%. A narrow zone around the North Sporades Islands and Skyros Island is dominated by sand, occasionally >80%.

The sediments of the north Aegean Sea are generally characterised by low carbonate content (<20%; Figure I.38). In the continental shelf (water depth <130 m) and upper slope area (water depth 130-300 m) carbonate content is generally <20%, however, some elevated values appear around Thasos Island, offshore of the Evros River mouth and around Samothraki Island. Relatively higher values are observed in the central part of the Thermaikos Gulf, the Sporades Basin and particularly in a zone surrounding the North Sporades Islands, where carbonate content exceeds 80%.

Coastal areas

Grain-size data are available for a number of semi-enclosed gulfs and coastal areas, namely the Pagasitikos Gulf, the Maliakos Gulf, the north Evvoikos Gulf, the south Evvoikos Gulf, the Petalioi Gulf and the Saronikos Gulf. Sediments of these gulfs are generally muddy sands and muds (Figure I.35).

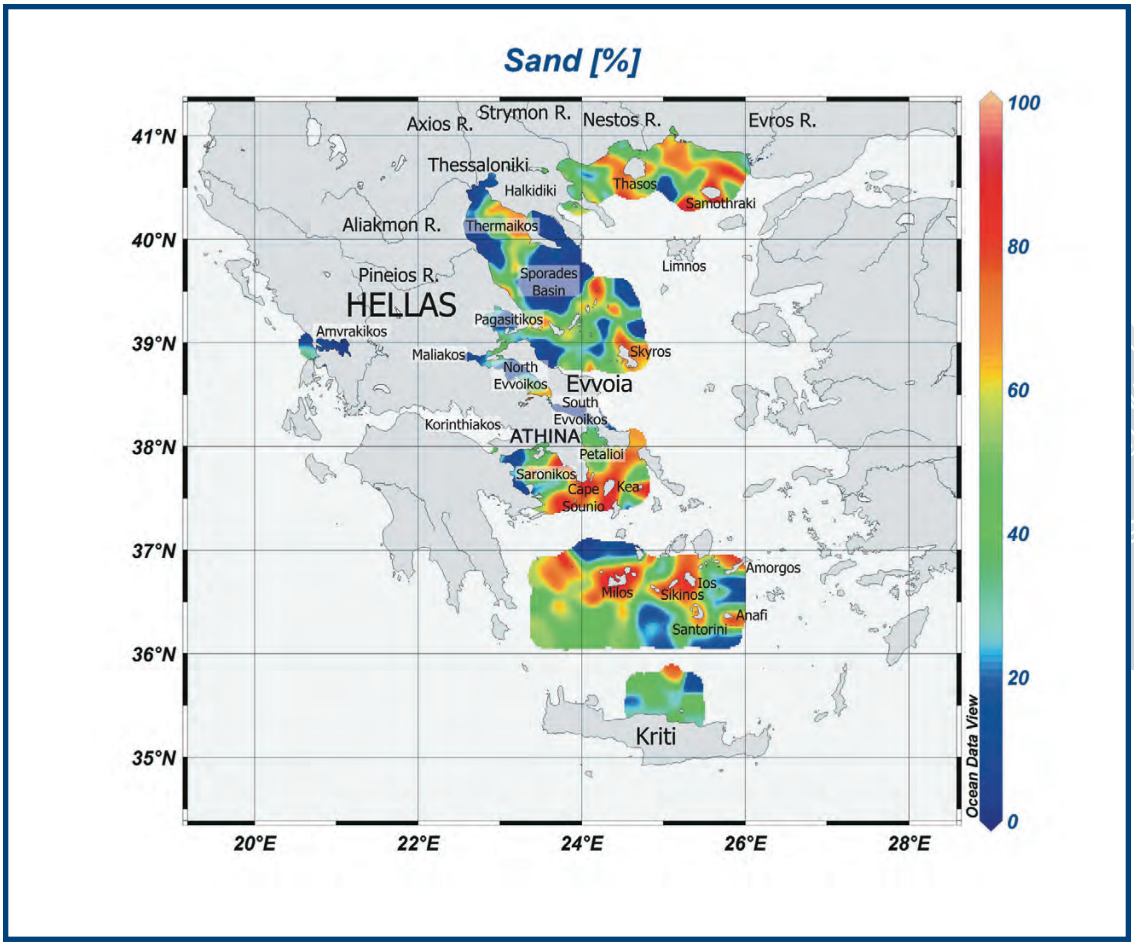


Figure I.35: *Spatial distribution map of dry weight percentage of sand in the Hellenic Seas.*

The Pagasitikos, Maliakos, the northern sector of north Evvoikos and south Evvoikos gulfs are covered by muddy sediments with high silt and clay contents (>40, and >30%, respectively; Figures I.36, I.37), and lower sand content (<30%; Figure I.38). The sediments of the western Saronikos Gulf

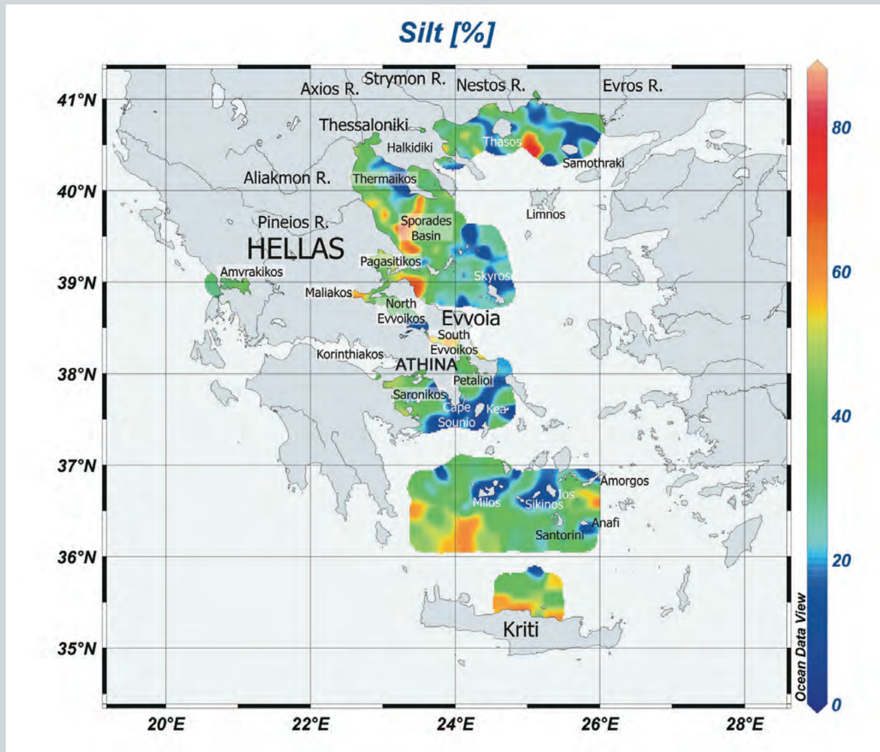


Figure I.36: *Spatial distribution map of dry weight percentage of silt in the Hellenic Seas.*

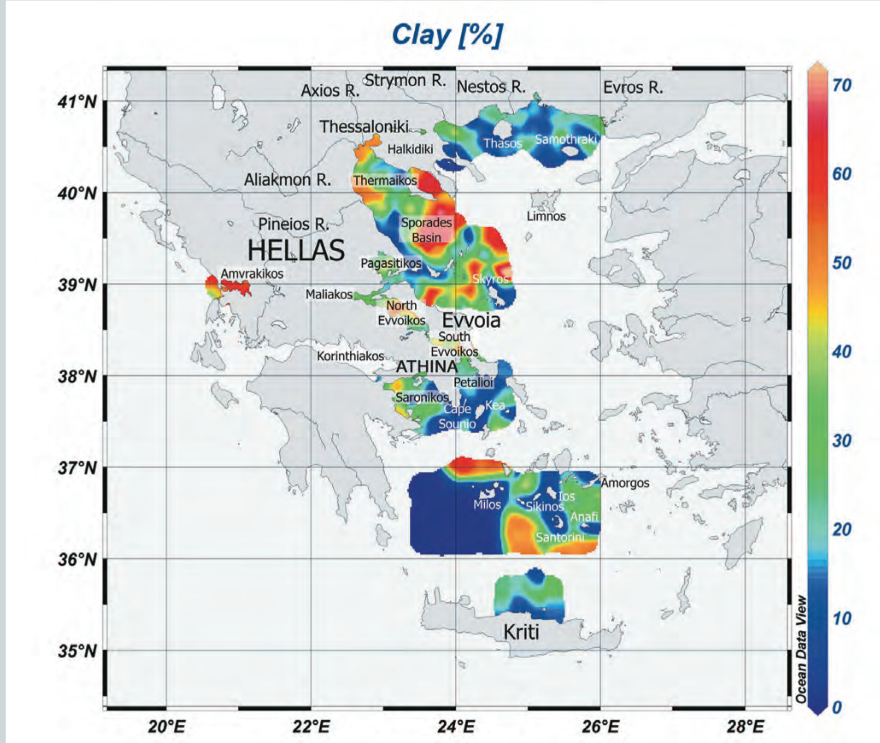


Figure I.37: *Spatial distribution map of dry weight percentage of clay in the Hellenic Seas.*

also show a similar texture. In the central and southern sector of the north Evvoikos Gulf coarser sediments predominate, with relatively elevated sand content. In the Petalioi Gulf, sand content gradually increases from the north (~40%) to the south and to the east (>80%), where silt and clay contents decrease. A zone of high sand content, often exceeding 90%, extends from the outer Saronikos Gulf to Cape Sounio, Kea Island and the southern tip of Evvoia Island.

Carbonate content is relatively low in the gulfs of Pagasitikos, Maliakos, north Evvoikos (northern sector) and south Evvoikos (<40%; Figure I.38). In the central and southern sector of the north Evvoikos Gulf, carbonate content increases up to 70%. In the Petalioi Gulf, carbonate content increases gradually from the north to the south and to the east, reaching high values (>80%). Similarly, a high carbonate content is observed in the central and outer Saronikos Gulf, and in the area between Kea Island and the southern tip of Evvoia Island.

Cretan Sea and South Kyklades Islands

Sediments collected from the south Aegean Sea cover the southern part of the Kyklades Islands, the northern part of the Cretan Sea and a part of the central offshore sector north of Kriti Island. The sediments of this region are mainly composed of sand and silt, and minor clay content. They are classified mainly as sandy muds and muddy sands (Figure I.34).

Sediments around Milos, Sikinos, Ios, Santorini, Anafi and Amorgos islands are characterised by high sand content (>80%), with the volcanoclastic component predominating around Milos and Santorini (PERISSORATIS *et al.*, 1995) and the biogenic component in the rest of the area (Figure I.35). Offshore sand decreases to 60-70%, while further offshore it is even lower (<40%). The silt content is up to 70%, the higher values are observed mainly in the Cretan Sea in the area between Kos, Santorini and Anafi islands, whereas lower values are recorded around the South Kyklades Islands, Kos and Anafi (Figure I.36). The clay content is also up to 60%, the higher values observed in the deep areas south of Santorini and Anafi islands, and north of Milos Island. Lower values occur in the rest of the area (Figure I.37).

The carbonate content exhibits high values (60 to >80%) in the areas where the biogenic component predominates in the sand fraction (Figures I.35, I.38). In contrast, the area south and southeast of Sikinos and Amorgos islands is characterised by relatively lower carbonate content (generally <50%).

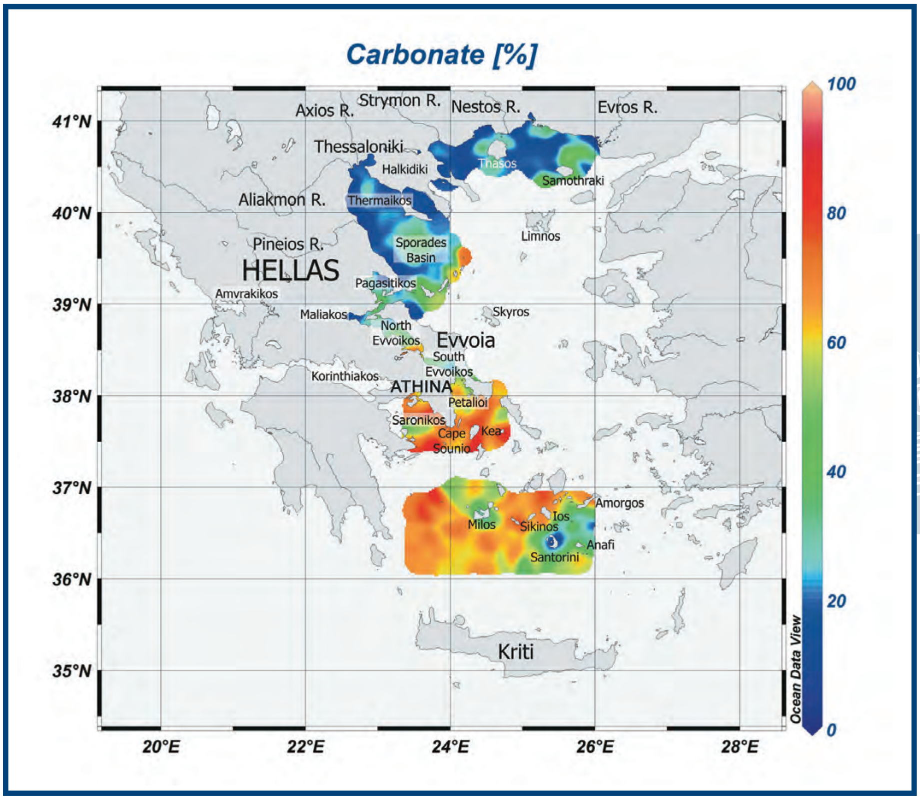


Figure I.38: *Spatial distribution map of dry weight percentage of carbonate content in the Hellenic Seas.*

Ionian Sea

Available data from the Ionian Sea are restricted in the semi-enclosed Amvrakikos Gulf, which receives substantial terrestrial inputs from the rivers Louros and Arachthos. Surface sediments are represented by muds and clays (Figure I.34), with clay being the predominant fraction, generally exceeding 50% (Figure I.37), the silt content ranging between 30 and 50% (Figure I.36), whereas the sand content is low (<20%; Figure I.35).

FACTORS CONTROLLING SEDIMENTATION

River supply

The creation of Quaternary alluvial plains is related to sediment discharge of major rivers, e.g. Axios, Aliakmon, Strymon, Nestos, Evros, Spercheios, Louros and Arachthos. In those areas most of the coarse-grained material is deposited within the alluvial plain and in the proximity of the river mouths, at depths generally <10 m. Fine sand and muddy sediments are transported by the wave action and the littoral currents further offshore to the continental shelf, whereas minor quantities are transported towards the shelf break, the slope and the deep basins. Coarse sand sediments settle in a narrow zone near the major rivers discharge points in shallow waters, where samples were not widely available. In the immediate vicinity of the river mouths (water depth 10-30 m) sand content appears to be generally in the range 10-40%, as for example, in the Thermaikos Gulf, Strymonikos Gulf, etc. In those regions the most abundant grain-size fraction is silt (30-60%), followed by the clay fraction (20-40%), the latter being more pronounced in the Thermaikos Gulf. This preferential sorting is clearly illustrated in the grain-size distribution of the northern Aegean Sea sediments. During the Holocene, continuous riverborne sediment deposition has resulted in the formation of sedimentary sequences (prisms) of several metres in thickness.

Similar distribution patterns are observed in the coastal areas drained by rivers of continuous flow (e.g. the Spercheios River discharging into the Maliakos Gulf, Louros and Arachthos rivers into the Amvrakikos Gulf) or ephemeral streams discharging into the Pagasitikos, north Evvoikos and south Evvoikos gulfs. In the latter areas muddy sediments predominate. In contrast, coastal areas not directly influenced by river supply or where major rivers are absent, the predominant sediment fraction is sand (Petalioi and Saronikos gulfs, coastal areas of the Cretan Sea). This high sand content is usually associated with high carbonate content, indicating that a considerable part of the sediment is composed of biogenic carbonates (shells and their fragments).

Bottom topography

As a general rule of thumb, sediments settle according to their grain-size inversely to the water depth, i.e. coarse sediments settle in shallow water, whereas finer sediments are transported offshore and settle in a quieter hydrodynamic environment. Thus, most of the clay fraction passing over the shelf break is deposited in the deeper areas. This pattern is generally recognised in the deep sectors of the northwest Aegean Sea and the Cretan Sea, where silty and clayey sediments cover the sea floor (Sporades Basin, the basin between Skyros Island and the North Sporades Islands, the open Cretan Sea). However, in the Cretan Sea the sand fraction appears to be substantially elevated mainly due to the presence of biogenic carbonates, and also due to the presence of volcanoclastic sediments (e.g. around the South Kyklades Islands). The same rule applies to the continental shelf as well, where theoretically the grain-size should be reducing by increasing water depth. However, on several occasions this pattern is interrupted by the presence of sand belts (central and eastern Thermaikos Gulf, Samothraki Plateau), a phenomenon related to the deposition of coarse-grained relict sediments during the last sea transgression as it will be discussed in a following section.

Circulation effects

The general sea water circulation in the Aegean Sea is cyclonic with several mesoscale features (cyclones and anticyclones) appearing on a permanent and/or seasonal basis. Circulation patterns mainly influence the transport of the fine sediment fractions (silt and clay). One example of the influence of this circulation is the grain-size distribution patterns in the northwest Aegean Sea (Thermaikos Gulf and Sporades Basin). Particulate matter supplied by the Axios, Aliakmon and Pineios rivers is transported along the western coastline in a narrow zone, as a result of the predominant cyclonic circulation. A portion of the particulate matter settles within this zone, whereas a minor part (~15%) escapes from the continental shelf into the deep Sporades Basin. Mesoscale features may also affect locally suspended particulate matter deposition patterns; anticyclonic eddies promote suspended particles accumulation and settling, whereas cyclonic eddies retard particle settling.

Sea-level changes

Sea-level oscillations during glacial-interglacial periods of the upper Quaternary are discussed in detail in Chapter III. Because of the rapid latest transgression of the sea, the Holocene terrigenous sediments were not able to cover the submerged areas, thus allowing older sediments to be preserved until today at the surface of the sea floor. Those sediments are named sensu lato relict and are presently abundant over the continental shelf of the northern Aegean Sea (PERISSORATIS, 1986), the Saronikos Gulf, the Petalioi Gulf and other areas. They are also characterised by a high carbonate content because they represent older nearshore deposits where various calcareous-shell organisms used to grow. The study of shallow penetration seismic reflection profiles showed that in the outer part of the Aegean shelf area, the post transgressive sediments usually comprise a relatively thin veneer (less than a few metres thick) deposited over a harder substratum, thickening in places where old river channels occur and narrowing off towards the shelf break.

Many studies have revealed that from the Holocene onwards, the sea initially intruded into all lowlands and gulfs and in most cases invaded farther inland than it is today. Gradually, however, these coastal river plains of Hellas were filled by terrigenous sediment input, with the land advancing seawards. As a result, the coastal morphology was greatly modified taking its present configuration. Characteristic examples of the latter process are the deltaic plains of the rivers Axios and Aliakmon in the northwestern Aegean Sea, the deltaic plain of the Spercheios River in the Maliakos Gulf, etc.

A SYNTHETIC EXAMPLE: THERMAIKOS GULF AND SPORADES BASIN-NW AEGEAN SEA

The northwestern Aegean Sea (Thermaikos Gulf and Sporades Basin) receives fresh water from the Axios, Aliakmon, Loudias, Pineios and other smaller rivers. During the latest sea-level lowstand, a substantial part of the Thermaikos Gulf was part of the mainland and the paleo-coastline was located several kilometres to the south, whereas a major paleo-river was flowing directly into the Sporades Basin (Figure I.39a). From 18 000 years before present (BP) and onwards, the sea progressively drowned the valley and at ~6 000 years BP the sea-level was relatively stabilised. Sediment supply from the rivers filled the northern sector of the gulf gradually and at ~500 AD the configuration of the coastline was roughly as we observe it today (Figure I.39b). The predominant circulation in the northwestern Aegean Sea is cyclonic (counter clockwise); Aegean waters entrain the gulf from the southeast, they move to the north along the eastern coast, where they mix with low salinity fresh waters and then follow a southward path, along the western coast (Figure I.39b). This prevailing circulation pattern controls the dispersion of suspended particulate matter which is introduced into the sea by the river system; high concentrations of particulate matter concentrations (~6 mg/l) appear in front of the river mouths and a narrow zone parallel to the western coastline (Figure I.39c), whereas little particulate matter is transported to the central and eastern sectors of the Thermaikos Gulf. As a result, sediment input and the general circulation are greatly influencing sedimentation patterns in the Thermaikos Gulf, illustrated in the distribution of sand content (Figure I.39d). Fine-grained material (silt and clay) predominates in the northern and western sectors of the gulf, as well as in the deep Sporades Basin. In contrast, sandy sediments prevail in the central and eastern sectors of the area. These are relict sediments which were deposited during the latest transgression, while the major paleo-river was retreating to the north (CHRONIS, 1986; KARAGEORGIS & ANAGNOSTOU, 2001). These old deposits remained uncovered, or have been partially mixed with modern sediment, because of the circulation regime and the absence of large rivers on the eastern coast.

CONCLUSIONS

Grain-size properties and carbonate content of the Hellenic Seas surface sediments display great diversity in terms of ranges and spatial distribution patterns. Coastal areas influenced by continuous river supply are generally characterised by fine-grained muddy sediments, the grain-size becoming finer in an offshore direction, where water depth increases. The finest clay sediments are transported in suspension towards the deep basins under the forcing of the general circulation patterns, where they finally settle. Their carbonate content is largely a function of biogenic activity, as it originates mainly in calcareous skeletons of marine organisms, as well as from the erosion of carbonate rocks on land and on coastal formations. Relict sediments enriched in carbonates are associated with the latest sea-level lowering and the following rise. They are found exposed at the surface of the sea floor at several sectors of the continental margins and areas receiving low terrigenous inputs.

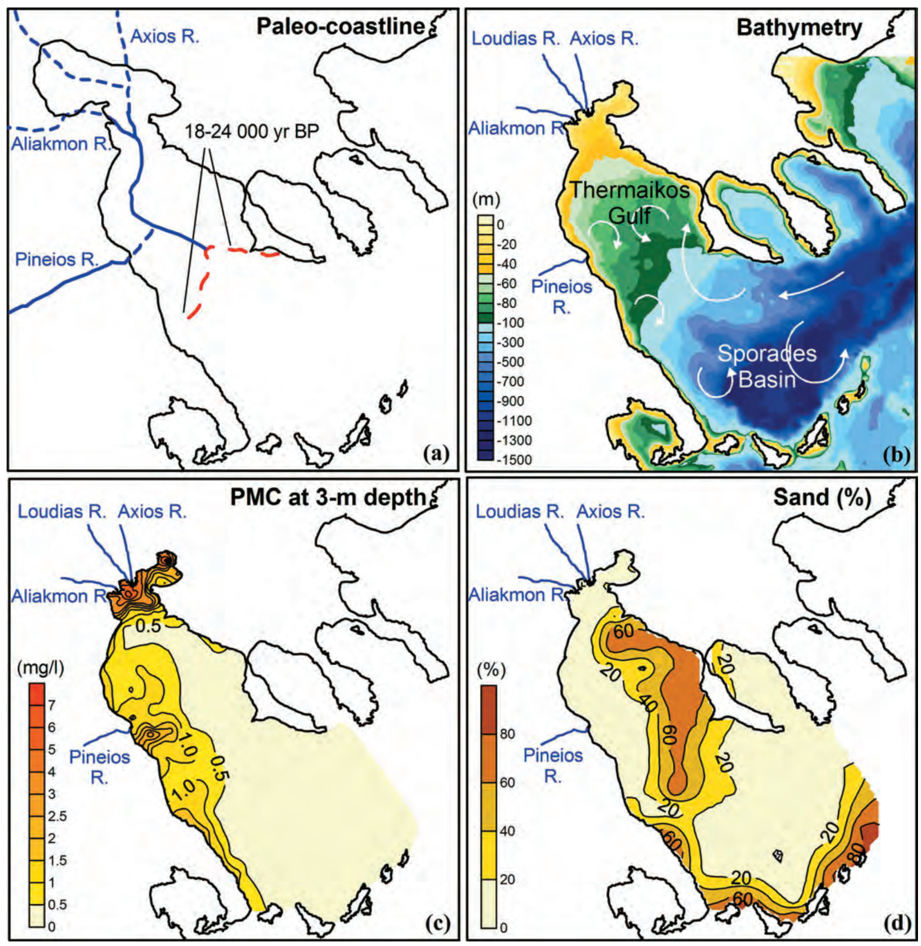


Figure I.39:
***a:** Configuration of the paleo-coastline (dashed red line) and the paleo-river system (dashed and solid blue lines) in the northwestern Aegean Sea at 18-24 000 years BP (LYKOUSIS et al., in press), **b:** bathymetric map of the northwestern Aegean Sea and mesoscale circulation patterns on the surface (KARAGEORGIS & ANAGNOSTOU, 2001, 2003), **c:** spatial distribution of particulate matter concentration (mg/l) at 3-m depth during May 1997; higher concentrations are observed near the river mouths and a zone parallel to the western coastline, **d:** spatial distribution of the sand content (%) in the northwestern Aegean Sea (KARAGEORGIS et al., 2005); note the predominance of sand in the central and eastern sectors of the gulf (relict sediments). High sand content near the North Sporades Islands is due to biogenic debris.*

I.5. PALEOCEANOGRAPHY AND PALEOCIRCULATION OF THE AEGEAN SEA FROM THE LATE GLACIAL PERIOD TO THE PRESENT (20 000 YEARS)

Traditionally, Aegean Deep Water (**ADW**) formation is considered to be of minor importance to the deep-water ventilation of the open eastern Mediterranean (WÜST, 1961). However, recent studies show that specific (cold) climatic forcing over the Aegean Sea has, throughout the 1990s, caused ADW to replace Adriatic Deep Water (**ADW**) as the main deep water in the open eastern Mediterranean (Chapter III.3). The dense water of Aegean origin has filled the deepest part of the eastern Mediterranean, changing dramatically its hydrological characteristics. According to a scenario, when the Aegean flushing returns to a low level, sea bed oxygen-depletion could be developed over periods of decades to centuries, with serious effects on the sensitive Mediterranean ecosystems and climate (KLEIN *et al.*, 1999). The Aegean's rapid response to atmospheric forcing makes it an ideal case study for the analysis of deep-water formation and its relationship with climatic change.

Dramatic deep-water ventilation changes, on longer time-scales, are witnessed in the sedimentary record of the Aegean Sea, by the presence of sapropels (Figure I.40). These dark organic-rich layers are found throughout the eastern Mediterranean, the Tyrrhenian Sea and some parts of the western Mediterranean. They were formed throughout the past seven million years (myr), with at least 11 formed during the last 450 thousand years (kyr), (reviewed by ROHLING, 1994). The precise mechanisms leading to this unusual past accumulation of organic matter in the Mediterranean Sea are still a matter of debate. Their formation is related to a slow-down of deep-water ventilation. These reductions were, in most cases, caused by changes to much wetter climatic conditions at times of increased Northern Hemisphere insolation (precession cycle minima, BERGER & LOUTRE, 1994).

The timing together with the apparent rapidity of past changes in the Aegean Sea suggest a direct atmospheric link between the eastern Mediterranean hydrographic regime and the global glaciation/deglaciation phases. Understanding the mechanisms which drove past abrupt climate changes is important in order to predict potential future impacts of anthropogenic climate forcing on society.

PALAEOCEANOGRAPHY OF THE AEGEAN SEA

The Late Glacial Period (20 000 – 12 500 years BP)

The most recent Pleistocene glaciation reached its maximum at ~20 000 years **b**efore **p**resent (**BP**). During this **l**ast **g**lacial **m**aximum (**LGM**) extensive ice sheets, up to several kilometres thick, covered the northern parts of North America and Eurasia. While large amounts of fresh water were locked away in the continental ice sheets, global sea level was ~120 m below that of today (FAIRBANKS, 1989). At that time, around the northern shores of the Mediterranean and in the Levant, the presence of steppe-like and salt-tolerant plants suggest a low level of precipitation prevailed. Changes in the monsoon over east Africa led to a significant decrease in precipitation along the southern boundary of the Mediterranean, turning the Nile River into a low discharge, seasonal river. Air temperatures in the Mediterranean were seriously depressed, by 5˚-10˚ C in winter and 1˚-3˚ C in summer, compared to present-day temperatures. With decreased air temperatures, the Mediterranean **S**ea **S**urface **T**emperatures (**SST**) were also lower than today, by 6˚-10˚ C in winter, with generally smaller decreases in the summer.

The significant lowering of the sea level altered the water circulation in the Aegean Sea, when continental shelves and inter-islands ledges were subareally exposed (Figure I.41). Although isolated basins with limited surface circulation are often stagnant, geochemical data and isotopic data of benthic foraminifera in the Aegean Sea cores show that bottom waters were cool but well oxygenated during the last glacial period (CASFORD *et al.*, 2002). This condition probably reflects bottom water formation along the northern periphery of the Aegean Sea, where cool subpolar waters were further chilled during the glacial winters, causing deep-water formation, similar to the present. Pollen data also suggest that winter monsoons were intensified, which would increase the inflow of very cold air from the northeast. Finally, temperature and salinity estimates suggest that the vertical thermal gradient was reduced in the Aegean Sea, probably enhancing vertical convective mixing, thus oxygenation of bottom waters.

The Last Interglacial and Sapropel S_1 (12 500 years BP to present)

Sea level started to rise at ~18 000 years BP from

Figure I.40:
Sapropel layer (S_1) in an Aegean Sea core.

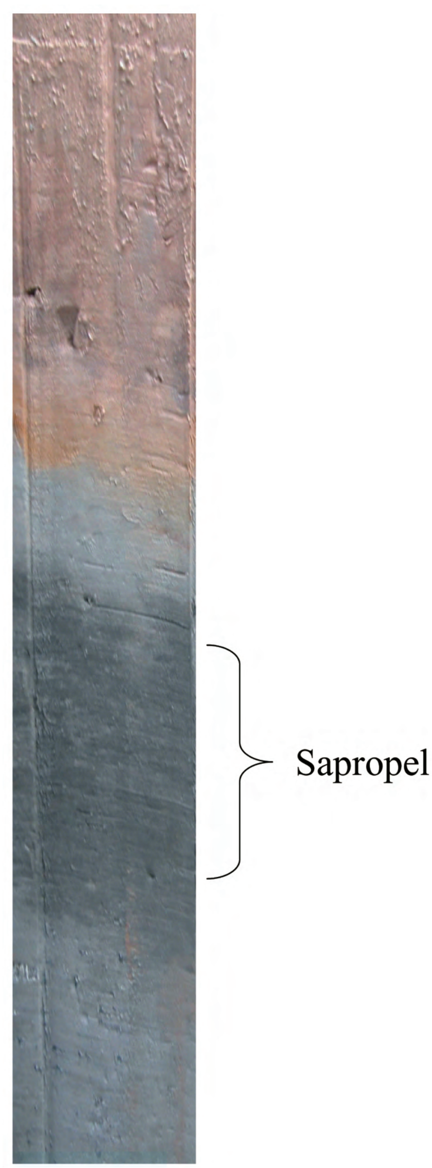
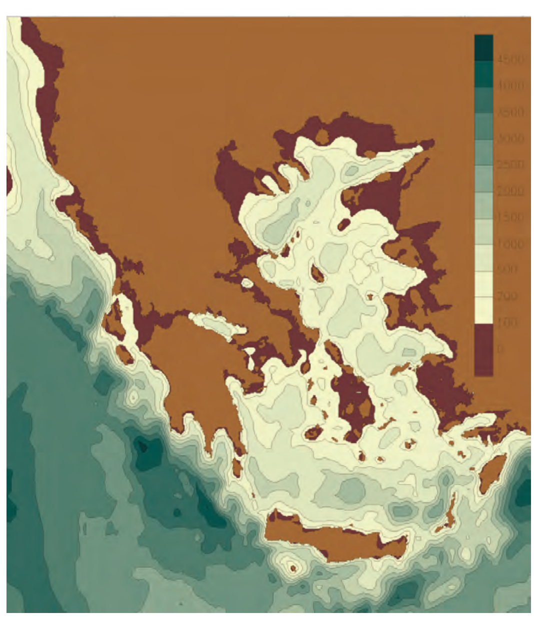


Figure I.41:
Sea-level stand and generalise paleomorphology of the Aegean region during the late glacial maximum (~18 000 20 000 years BP).



Source: *LYKOYSIS, 2003.*

a glacial maximum low stand of –120 m, reaching –95 m by ~12 500 years BP (FAIRBANKS, 1989). Between 12 500 and 9 000 years BP, global sea-level curves show two pulses of rapid sea-level rise, reaching –35 m by 9 000 years BP Present sill depths of the straits of Bosphorus and Dardanelles suggest that the first post-glacial linkage of the Black Sea and the Aegean Sea occurred between 9 500 and 9 000 years BP Between about 9 800 and 6 500 years BP, the Aegean Sea experienced a major phase of reduced thermohaline ventilation, which has been attributed to enhanced freshwater inputs and deposition of anoxic, rich in organic carbon sediments (sapropel S_1), took place (ROHLING, 1994). Several sources have been proposed for the increased freshwater inflow into the Mediterranean Sea:

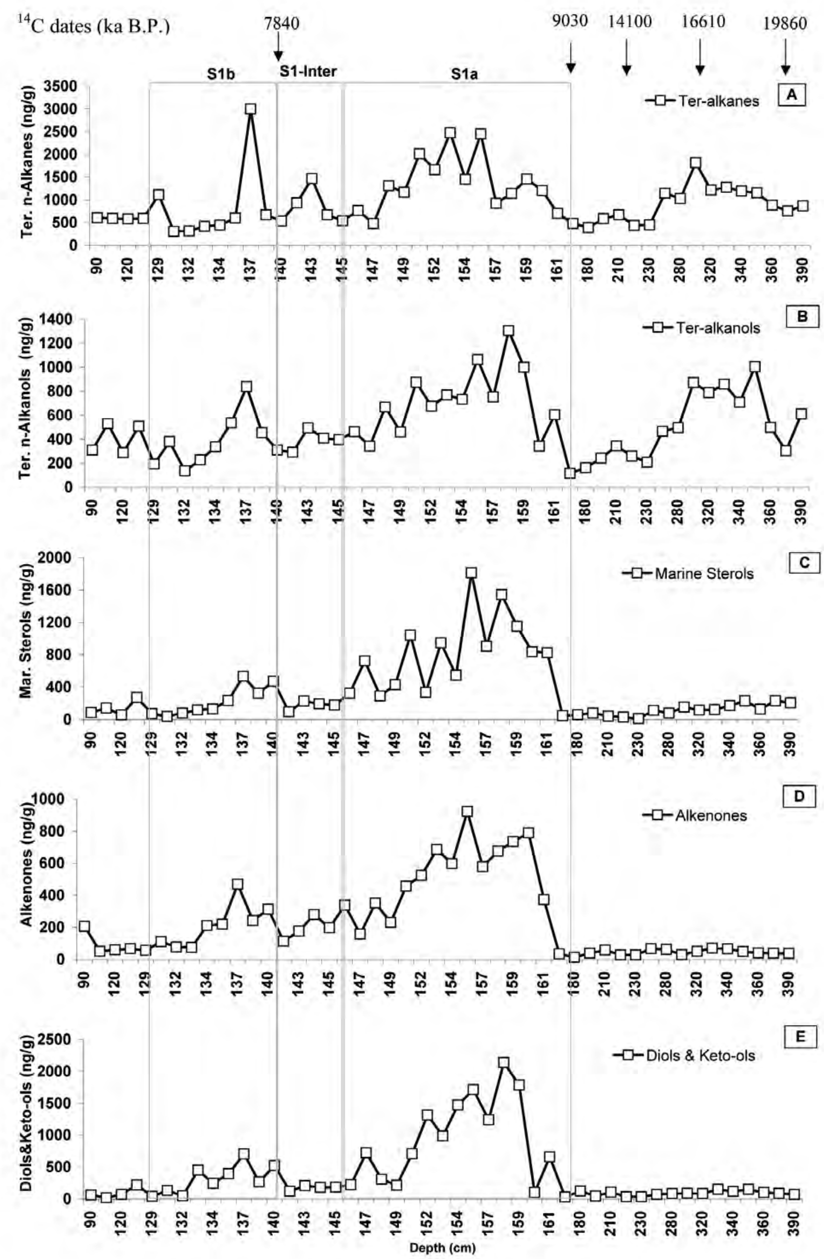
(1) glacial meltwater entering the Mediterranean via the Adriatic and the Aegean seas during the glacial–interglacial transitions;
(2) increased Nile River discharge rates caused by enhanced African monsoons;
(3) increased precipitation and fluvial discharge along the northern borderland of the eastern Mediterranean; and
(4) the opening of the straits of Bosphorus and Dardanelles and the flushing of Black Sea waters into the Aegean, after the last post-glacial sea-level rise. Increased freshwater influx would enhance nutrient concentrations in the basin that would in turn enhance productivity.

Two main theories have been proposed for the formation of sapropels. The stagnation/anoxia theory suggests that, during times of excessive freshwater influx into the Mediterranean Sea, the water column became strongly stratified, preventing vertical mixing and oxygen supply to the bottom waters, thus promoting preservation of higher percentage of the total organic carbon (**TOC**) and sapropel deposits with >2–5% TOC. Sapropel deposition was terminated when the vertical mixing and aeration of bottom waters were restored following cessation of the large freshwater influx. During these times siliciclastic and bioclastic sediments were deposited with generally less than 0.5% TOC. Because sapropels typically contain 5-10% organic carbon, anoxia alone cannot explain sapropel formation. In addition to the stagnation/anoxia theory, sapropel formation has also been associated with increases in export productivity. The high-productivity hypothesis argues that present-day biological production of organic matter in the Mediterranean Sea is insufficient to produce more than a few percent of organic carbon in sediments, even if the preservation of organic matter was perfect. Therefore, it has been proposed that sapropel deposition was caused by a rise in the flux of organic matter.

Recent studies showed that the stagnation/anoxia and increased biological productivity theories are not mutually exclusive, as an increase in productivity would enhance export of organic carbon (C_{org}) to the sediment surface and could utilise all the available oxygen, producing anything from dysoxia to anoxia. Thus, an enhanced primary production (e.g. coccolith and colonial diatom blooms) could have occurred with the increased influx of nutrients via rivers, or with a significant change in the water circulation patterns and could utilise all the available oxygen, producing anything from dysoxia to anoxia at those times. Finally, other authors based on chemical analysis, argue that sapropel deposition is related to deep brine lake formation processes.

Changes in stable isotope composition have led to considerable speculation on the variability of Mediterranean freshwater budgets. Studies of $\delta^{18}O$ of micro-faunal records (planktonic and benthic foraminifera) in cores on a north–south transect in the Aegean indicate a reduction in surface water salinity throughout the Aegean Sea during the deposition of S_1. Moreover, relatively light ^{13}C values of TOC and high pollen-spore concentrations in S_1 suggest increased influx of terrestrial organic matter from major rivers draining into the northern Aegean Sea. These observations, in conjunction with our results, showing high concentrations of terrestrial (Figure I.42 A & B) and planktonic (Figure I.42 C, D & E) organic biomarkers during the deposition of S_1, provide strong arguments that the nutrient supply and the Corg productivity/preservation was much improved during sapropel S_1 deposition compared to present-day (GOGOU *et al*., 2004). However, low Corg sapropels (≤2% Corg,), such as those found during the deposition of the Holocene S_1, could be produced without significant increases in primary productivity, i.e. without the development of a **D**eep **C**hlorophyll **M**aximum (**DCM**). Thus, true anoxia could have been also developed as a 'blanket' limited to the sediment/water interface.

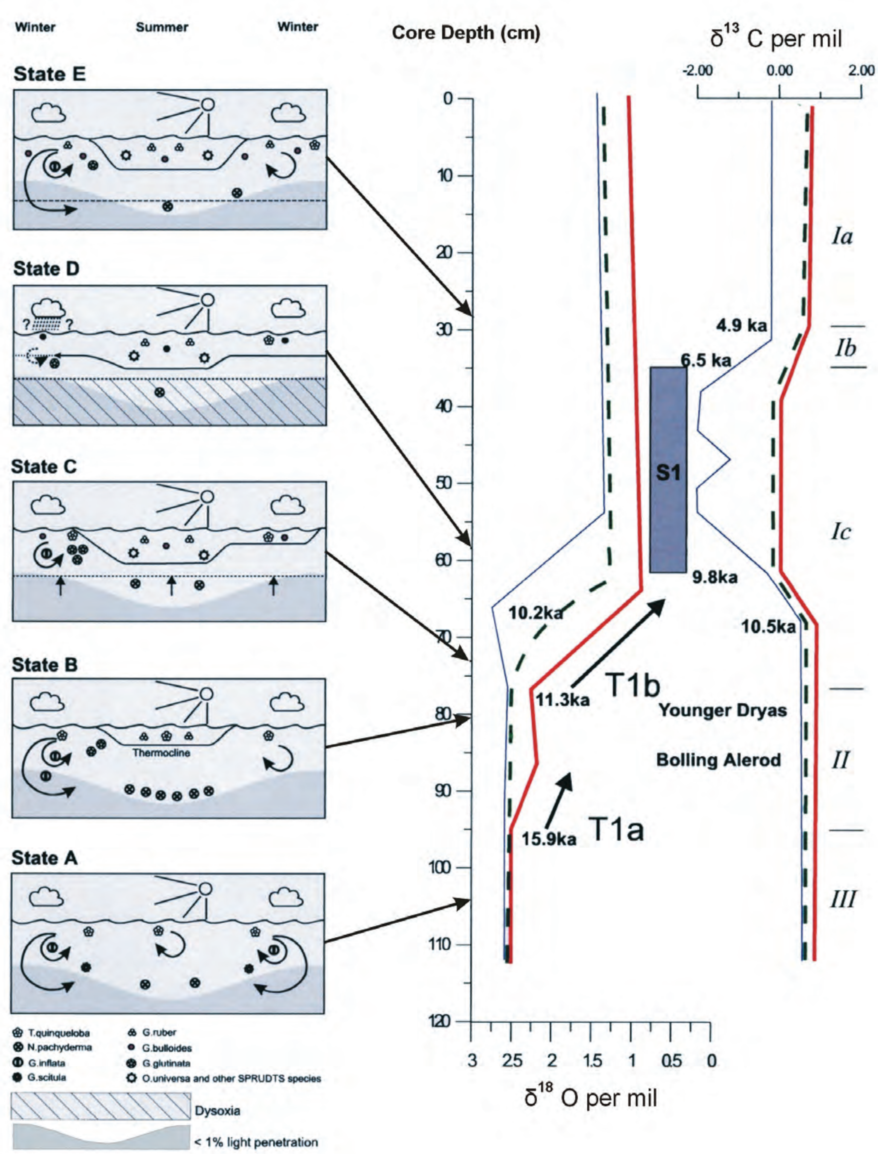
Modelling of circulation during the deposition of S_1 has suggested that relatively small increases in surface buoyancy can lead to suppression of deep-water circulation in the east Mediterranean Sea. In general, steady-state models assume that nutrients lost via Corg burial are continuously balanced by fluvial/aeolian influxes. However, it appears that steady-state models cannot import sufficient nutrients into the eastern Mediterranean, outside of the coastal regions and marginal seas, to sustain this accumulation. CASFORD *et al*., (2002), offer new observations within the context of previous modelling works to assess whether, at times of sapropel S_1 deposition, deep-water formation had ceased (or not) and to what extent dysoxic and/or anoxic conditions prevailed. These authors presented evidence, which suggests that the steady-state approach is seriously flawed and a significant period of potential nutrient accumulation in a stagnant basin may have preceded the actual sapropel deposition. They use abundance



Source: *GOGOU et al., 2004.*

Figure I.42:
Concentrations with depth of terrestrial n-alkanes (A), terrestrial n-alkanols (B), marine sterols (C), long chain alkenones (D), and diols & keto-ols (E) at Site MNB3 (north Skyros basin) in the north Aegean Sea. Deep grey shaded regions represent the sapropel S_1. Light grey shaded regions represent the S_1 interruption. White regions represent the period from the late last glacial period up to the S_1 deposition (~20 000 to 9500 ka BP) and the Holocene period above S_1 (~6500 ka BP to present).

variations of planktonic foraminifera together with species-specific oxygen ($\delta^{18}O$) and carbon stable isotope ratios ($\delta^{13}C$) in these species to derive a picture of the oceanographic processes leading up to, during and after the most recent sapropel deposition in the Aegean Sea. By using this approach, they show responses to hydrographic changes that may be several times greater than the corresponding changes in conservative properties, i.e. salinity. Finally, they propose a multi-proxy record to best interpret, in combination with the foraminifera abundance records, the series of successive, climatically driven, changes in dynamic regimes. These are illustrated as a series of transitory states alongside a schematic summary of the main isotopic changes recognised in the Aegean records (Figure I.43). Each state represents a single point in time, which may be considered



Source: *Modified after CASFORD et al., 2002.*

Figure I.43:
Schematic reconstruction of the history of Aegean circulation, showing changes in deep-water mixing in the Aegean since the last glaciation, alongside the major summarised changes in δ18O and δ13C isotopic signals of different benthic foraminifera species (ruber, pachytherma, inflata). The heavy red line indicates δ18Oruber, the lighter black line δ18Opachyderma, the dashed line δ18Oinflata and the vertical grey box indicates the extent of the benthic sapropel S1. All dates are expressed as calibrated radiocarbon convention ages, corrected for reservoir effect (thousand years before present - ka BP). The positions of the Younger Dryas and the Bölling Alerod events are also indicated.

typical of the particular climatic/circulation regime. These transitory states are described in brief below.

Delineation of mechanisms and timing of circulation changes in the last glacial/ interglacial Aegean Sea

State A (Figure I.43) is interpreted as typical of the glacial Aegean Sea. This period is characterised by a single well-mixed water mass with strong accordance between isotopic signals ($\delta^{18}O$ and $\delta^{13}C$) in all species analysed. This trend suggested little density contrast in the water column, while the presence of deep mixing species points to regular homogenisation/overturn of the water column, indicative of year-round mixing. The glacial circulation pattern appears to alter with the termination of isotopic stage 1a (T1a, Figure I.43). At that time, a shift in environment is clearly indicated in both the fauna and the isotopic data. The interpolated dates suggested the onset of this change at ~15 900 years B.P. (Figure I.43).

State B (Figure I.43), is typical of the regime that seems to mark the appearance of distinct seasonal stratification in the post-glacial Aegean Sea. During that interval, the first substantial occurrence of warm mixed-layer species was observed, suggesting a general sea surface warming. This trend lead CADFORD *et al.*, (2002), to suggest the development/strengthening of a stable summer thermocline in a generally well-oxygenated environment in the Aegean Sea. Studies of African lake levels and aeolian dust influxes suggest that this period also saw the start of a regional humidity increase (**A**frican **H**umid **P**hase, **AHP**). Any increase in freshwater budget would have increased surface buoyancy, helping to establish seasonal stratification. This period persisted until ~12 500 years B.P. After this period and in common with the North Atlantic records, a plateau in the $\delta^{18}O$ values shows the appearance of the **Y**ounger **D**ryas (**YD**) period also in the Aegean Sea records, representing a cool arid climatic event. The YD conditions continue until the start of termination 1b, marked at ~11 300 years BP. With the ending of the YD, the AHP recommenced and persisted until 5 500 years BP In the Aegean cores, a depletion in $\delta^{13}C$ is recorded for all species, starting at ~10 500 years BP, which has been interpreted as a result of increasing humidity in the Aegean Sea (**State C**, Figure I.43). This may be tentatively explained in terms of increased freshwater input, which reduced surface buoyancy loss and hence suppressed mixing. The start of sapropel production, occurred ~1 500 years after the isolation of the deep/intermediate waters (**State D**, ~9 800 years BP, Figure I.43). The isolation of subsurface waters would have allowed subsurface accumulation of remineralisation products over a period of up to 1 500 years, before these products became available for production in the euphotic zone. CASFORD *et al.*, (2002), suggested that this long-term accumulation provided a major source of excess nutrients that could sustain enhanced productivity during sapropel deposition. Based on benthic foraminiferal indicators, S_1 persisted until 6 500 years BP The sapropel mode ended with the reoccurrence of winter mixing indicative species at ~ 6 500 years BP, while the return to a modern faunal assemblage was completed by ~4 900 years BP (**State E**, Figure I.43).

CONCLUSIONS

Paleoclimatic studies in the eastern Mediterranean and Aegean Seas have shown that climatic transitions are often periods of great instability, marked by abrupt changes of environmental parameters. At times of sapropel S_1 formation (~9500 to 6500 yrs BP), the strong humidity/runoff increase, affecting the Mediterranean Basin, caused a serious reduction in the net evaporation that is so critical in the first stage of deep ventilation. An increase of 20-30% in the freshwater budget could be enough to allow interruption of deep-water production in the Aegean Sea. The increase of nutrients loadings to the basin, lead to enhance productivity in the surface waters, as revealed from biomarker and nanofossil studies, showing that the organic matter production and flux was increased relative to the present. Organic matter that rapidly sank to the sea floor was subjected to minor/no oxidation in the old deep-water mass and it consequently became preserved and buried in the sediments. Finally, benthic faunas and their isotopic fractionations ($\delta^{13}C$ and $\delta^{18}O$) data from Aegean sediment cores, added evidence to the hypothesis that the bulk of the water column (at least down to 2 000 m) was never completely anoxic during S_1 formation, but that true anoxia (as reflected in the sediments) was restricted to a thin layer of water at/above the sediment surface. In respect to this, any burst of ventilation could temporarily reoxygenate deep waters, leaving sufficient bio-available oxygen to support benthic organisms.

Being a semi-enclosed marginal basin of relatively small volume (compared to the open ocean), the Aegean Sea shows amplified and very rapid response to climate change. Consequently, climate signals are well expressed in the Aegean Sea, and in the case of the glacial-interglacial contrast. Moreover, the north Aegean Sea, shows generally elevated sedimentation rates and reduced sediment mixing, relative to the open ocean, especially during the special times in the past when the bottom waters became anoxic. These attributes make the Aegean Sea an excellent site for the investigation of changes in past climate and hydrographic response, at high (decadal- to centennial-scale) temporal resolutions.

I. GAPS IN KNOWLEDGE - FUTURE PERSPECTIVES

A lot of fundamental work still needs to be done towards understanding the geological structure below the Hellenic Seas. Swath bathymetric surveys combined with systematic seismic profiling will improve our knowledge on the possible occurrence of natural marine geo-hazards like offshore seismicity, fault ruptures, submarine landslides and tsunami generation, which may constitute a serious threat for the coastal zone.

Coasts are under pressures, facing complex development dilemmas. A deeper understanding of the coastal morphodynamic processes is needed. In the future and in order to comply with the principles of the ICZM (socio-economic solutions and sustainable development) we need to identify/study anthropogenic activities (urbanisation, industrialisation, aquaculture and tourism), as well as physical processes (sea level rise and erosion) that may alter the physiognomy of the coastal areas and model their affects on the coastal and marine ecosystem.

Despite the abundance of sedimentary data mainly from coastal areas, which exist in the literature, there is a clear lack of sedimentary data regarding the deep seas. Both the central Aegean Sea and the Ionian Sea have not been studied in detail, as far as all aspects of sedimentology are concerned. A large-scale project should be undertaken in the near future at a national level, in order to investigate the deep Hellenic seas. HCMR and IGME could coordinate this effort and provide fundamental information on the diverse properties of the Hellenic sea floor.

There is a need for further investigation regarding the past climatic and consequently the paleooceanographic conditions in the Aegean and the eastern Mediterranean Sea through the study of specific proxies (forams, pollen, biomarkers, nanoplankton, etc.). Particular attention should be paid to the study of sapropelic layers and their interruption that reflects periods of limited oxygenation and water column stratification and reoxygenation. The Aegean Sea provides a unique case study for deep-water formation processes and also for climatic functioning, due to the magnification of the effects of environmental response to abrupt climate shifts.

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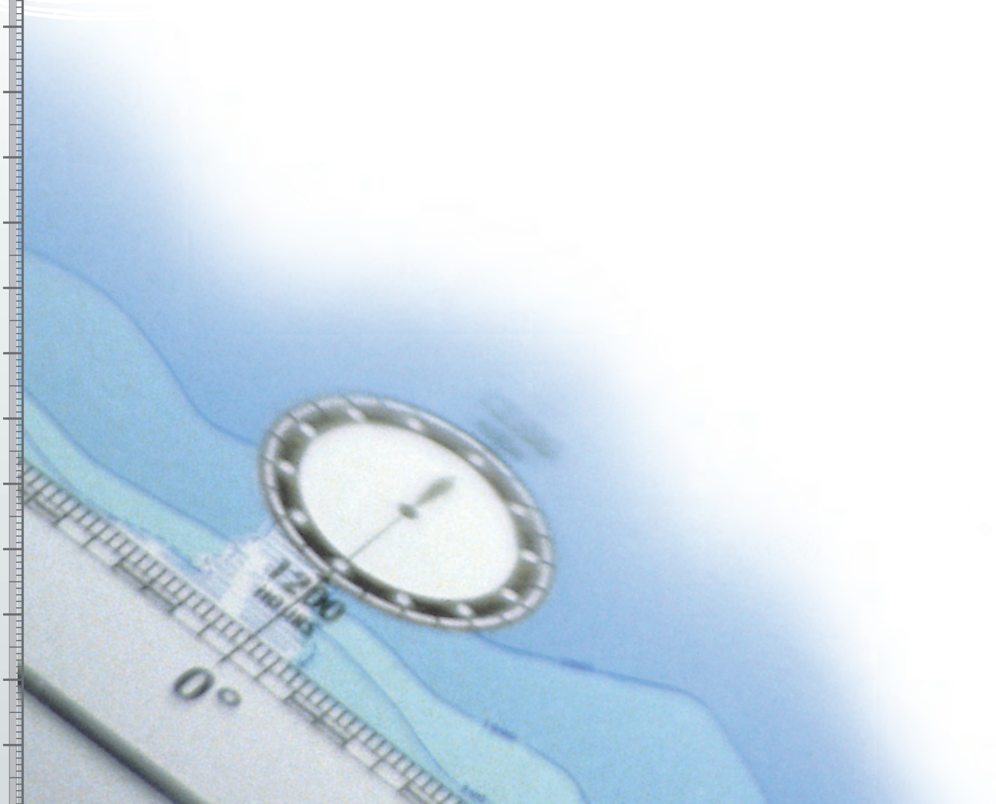
CHAPTER II
AIR-SEA-LAND - SYSTEM



II. THE AIR-SEA-LAND -SYSTEM

INTRODUCTION

The atmosphere and the ocean form a joint system driven by the external forcing of the energy received from the sun. Both systems are in continuous motion attempting to balance the uneven horizontal distribution of the net incoming radiation. This is accomplished through the advection and convection of heat, momentum and moisture. As a consequence, energy is transferred from the atmosphere to the ocean surface mixed layer driving the circulation of the upper ocean, while energy from the ocean is fed back into the atmosphere affecting the atmospheric circulation and consequently the weather and climate.

Over the eastern Mediterranean Sea and its sub-basins, the ocean and marine atmosphere interact and influence major human habitats. The ocean is driven by the atmospheric forcing through the energy input from the surface winds, the changes in ocean water buoyancy due to the air-sea fluxes of radiation (solar and long-wave radiation), heat (latent and sensible) and fresh water (expressed primarily as precipitation minus evaporation). The ocean mostly affects the atmosphere through the sea surface temperature variability, which controls the upward long-wave radiation and the sensible and latent heat fluxes. In addition, the roughness of the sea surface can also affect the efficiency of near-surface turbulent exchange.

In the entire Mediterranean, the overall excess of evaporation, over precipitation and runoff, combined with a slight mean loss of heat through the surface, leads to inflow of Atlantic water at the surface in the Straits of Gibraltar and outflow of saltier, cooler water at depth, originally formed in the eastern Mediterranean (Figure II.1). Therefore, the surface heat and freshwater exchanges are directly connected to the flux of heat and water through the Straits of Gibraltar and the characteristics of the Mediterranean water outflow into the Atlantic Ocean.

Figure II.1 represents a rough picture of the physical atmospheric forcing of the Mediterranean, which sets the system into circulation. Details of the response of the eastern Mediterranean to the surface forcing will be provided in Chapter III. In this Chapter, various aspects of the air-sea interaction in the eastern Mediterranean and the Hellenic Seas will be examined in the following order:

In Section II.1 the mean state and seasonal variability of the regional weather and climate systems will be described. The resulting long-term mean atmospheric fluxes into the ocean and their seasonal variability will be analysed in Section II.2. Section II.3 describes the momentum exchanges in the Aegean and the resulting wave fields in particular. The tides in the area produced by the astronomical forcing are discussed in Section II.4, while the air-sea exchanges of nutrients, pollutants and particulate matter fluxes are examined in the last two Sections II.5 and II.6.

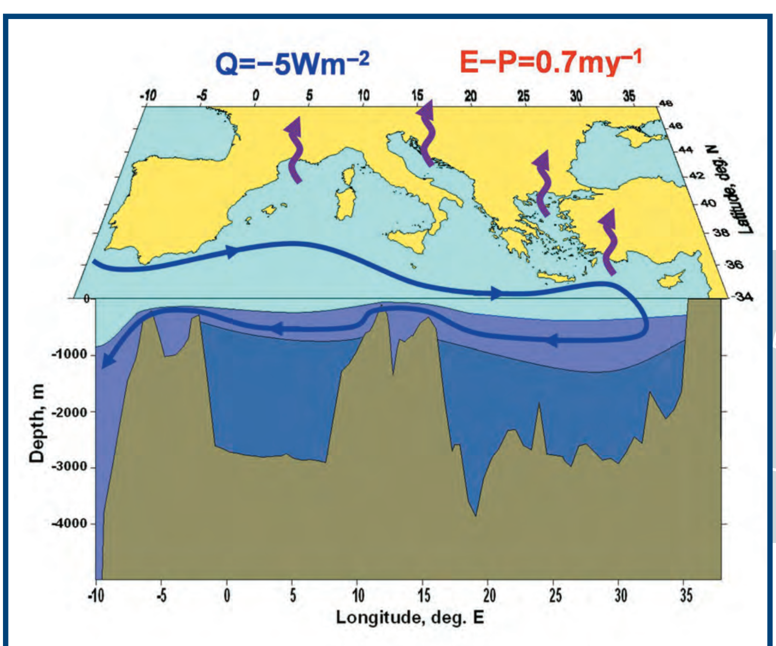


Figure II.1: Schematic of the Mediterranean buoyancy driven circulation. Q represents the total annual heat loss over the surface of the Mediterranean, while E-P is the freshwater deficit as evaporation exceeds precipitation and river runoff.

II.1. WEATHER SYSTEMS

The weather conditions over the eastern Mediterranean basin are controlled mainly by the seasonal movement of the semi-permanent large pressure systems developed over the Atlantic, Europe, Asia and North Africa (e.g. the Azores anticyclone, the Siberian anticyclone, the anticyclonic activity of the central Europe) and their interaction with the Polar Front Jet and the Subtropical Jet. However, the significant variations of the physiographic characteristics in the region in the form of topographic features and land-water distribution, are responsible for the development of atmospheric circulation features at smaller scales which are imposed on the synoptic scale flow. As a consequence, the weather characteristics exhibit significant temporal and spatial variations within the basin.

The climate of the eastern Mediterranean can be distinguished into two seasons with transition periods between them. The broad characteristics of these seasons are:

- The winter season (November to February), which is the rainy period exhibiting strong cyclogenetic activity.
- The summer season (June to September), characterised by anticyclonic activity. Although, the weather is more uniform, locally produced atmospheric circulations are often quite strong altering accordingly the weather patterns in the region. The period is dry almost with no rain. However, thunderstorms frequently occurr in the region.
- The periods between March to May and September to November are the transition periods from one season to the other. However, neither the beginning nor the duration of the transition period is constant.

THE WINTER PERIOD

During the winter season, the weather in the eastern Mediterranean basin is characterised by the passage of depressions, which are sometimes blocked by stationary areas of high pressure. The high-pressure systems, which dominate the region, are the semi-permanent Azores anticyclone to the west and the seasonal Siberian anticyclone with its extensions to the northeast, formed because of the intense cooling of the Eurasian landmass during this season. During winter, the general westerly circulation of the anticyclones moves southwards, allowing the Atlantic depressions to move across northern Europe bringing cold moist air, frequently penetrating into the Mediterranean and encountering warm moist air. These atmospheric conditions favour the cyclogenetic activity (formation of depressions) over the Mediterranean Basin in specific locations mainly within the western Mediterranean.

The preferred tracks of cyclones originating over the Gulf of Lions, the Gulf of Genoa or the north Adriatic Sea takes them over the eastern Mediterranean thus affecting the weather in the region. The primary cyclone track from all three occasions, starting from the cyclogenesis centre, passes across southern Italy, continues towards Greece moving over the Aegean Sea and then turns northeast towards the Black Sea. Another frequent track is related to the cyclones developed over the desert region south of the Atlas mountain ranges of North Africa. The North African cyclones transferring tropical air masses move eastward along the coast or enter into the eastern Mediterranean. Cyclogenesis may also occur in the Cyprus area, when the southward movement of a cold front deflects on the Taurus Mountains of Turkey generating a depression along the southern slopes.

Because of the frequent passage of depressions, the west part of the eastern Mediterranean region is characterised by high rainfall. The rain patterns correspond with the areas where the cyclone tracks pass, with the Ionian Sea receiving much more rain than the Aegean Sea. This is expected since the main mountain ranges of the Hellenic Peninsula have an orientation from north to south, which is vertical to the main Mediterranean cyclone tracks, thus blocking the moisture paths.

The passage of surface low-pressure systems with associated high-pressure systems covering the Balkan Peninsula as an extension of the Siberian anticyclone or shifting of the anticyclonic activity of the central Europe south-eastward, causes a northerly flow prevailing in the Aegean Sea. Due to the nature of the surrounding terrain, bora type winds[1] often blow in the Aegean Sea with north to northwest directions. This bora type wind, locally called Vardares, is cold and strong, reaching gale to storm-force strengths, flowing through the mountain passages of the Vardar Gaps. The flow is confined to the Aegean Sea by the Rodopi Mountains to the north, the Pindos mountain chains to the west, and the western Turkish mountains to the east. The extension of the flow from the Aegean Sea to the eastern Mediterranean is associated with the cold outbreaks from the north to the northeast Mediterranean and depends on the depth of the cold air mass (KALLOS *et al.*, 1996). If the cold air is sufficiently deep the flow moves southwards and over the Aegean island complexities, changes its direction to northwest, due to channelling and obstacles effects, crosses Kriti and moves into the eastern Mediterranean with west to northwest direction.

When cyclogenesis occurs in North Africa, then the Sirocco wind blows in front of the low-pressure centre that travels eastwards over the southern Mediterranean. The Sirocco is a warm wind with southeast to southwest direction, dry in its origin, but becoming moist when it picks up moisture crossing the Mediterranean and, therefore, is associated with heavy rain and cloudiness.

Extreme Weather Events

Sometimes migratory cyclones generated in the western basin or the Adriatic Sea remain stationary in the Ionian Sea and the southern Aegean Sea where they rejuvenate. The occurrence of these depressions is a rather rare event. However the large temperature differences between the cold continental air mass and the relatively warmer sea surface may lead to these depressions producing abundant rain in the region. The energy supply required for the maintenance and intensification of these systems is provided as latent heat flux, while moisture flux provides the necessary amount of water vapour to sustain precipitation. Some cyclones develop so explosively that they became known as meteorological ‘bombs’ (SANDERS & GYAKUM, 1980). The characteristic features of such a ‘bomb’ are the rapid central pressure reduction, an attendant increase in intensity, and the requirement of extremely strong release of latent heat (ZHU & NEWELL, 1994). An example of such a ‘bomb’ over Hellas is the storm of January 2004 which occurred over the central Aegean Sea. Model analysis, using the POSEIDON weather forecasting system[2] (PAPADOPOULOS *et al.*, 2002), indicates that the latent heat flux acting to fuel the system may exceed 1200 Wm^{-2} (Figure II.2).

When low pressures cover Asia Minor and the eastern Mediterranean, continental polar air masses may be brought from the northeastern Europe towards the Balkan Peninsula resulting in relatively northeastern winds, very low temperatures, cloudiness and snowfalls, even in southern Hellas. Figure II.3 shows the POSEIDON forecasts for the snowstorm which occurred on 12-13 February 2004.

THE SUMMER PERIOD

During the summer period, the main climate patterns affecting the weather in the eastern Mediterranean basin are the Azores anticyclone which intensifies developing an extension towards central Europe and the thermal low over the Anatolian plateau which develops because of the intense heating over the dry land. Meanwhile, the general circulation moves northward resulting in the weakness of the Atlantic cyclones, shifting their tracks northerly. In addition, since the surface waters of the Mediterranean Sea are relatively cooler compared to the temperatures of the surrounding land, high pressures dominate in the region. The atmospheric conditions favour settled weather, characterised by clear skies and almost no rain. However, a trough or the edge of a cold front passing over northern Hellas may cause

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[1] Bora is a northern katabatic wind in the Adriatic, Hellas and Turkey that blows down a topographic incline such as a hill or mountain.

[2] The POSEIDON weather forecasting system is based on the SKIRON/Eta model, which is an evolution of the 1997 version of the National Centers for Environmental Prediction (NCEP) Eta model. It is fully operational since October 1999, providing daily high-resolution (currently at 10 km) 72-hour weather forecasts for the eastern Mediterranean.

unstable conditions associated with the co-existence of convergence zones leading to intense convection in the area and heavy convective rainfall is evident in the area. An example of the development of such an intense convective rainstorm in June 1999 is shown in Figure II.4 .

The Etesian winds are strong northerly winds prevailing in the Aegean Sea and the eastern Mediterranean Sea, bringing cold continental air. They blow between May to October with maximum intensity and frequency during July and August. The Etesian winds are considered as a part of the

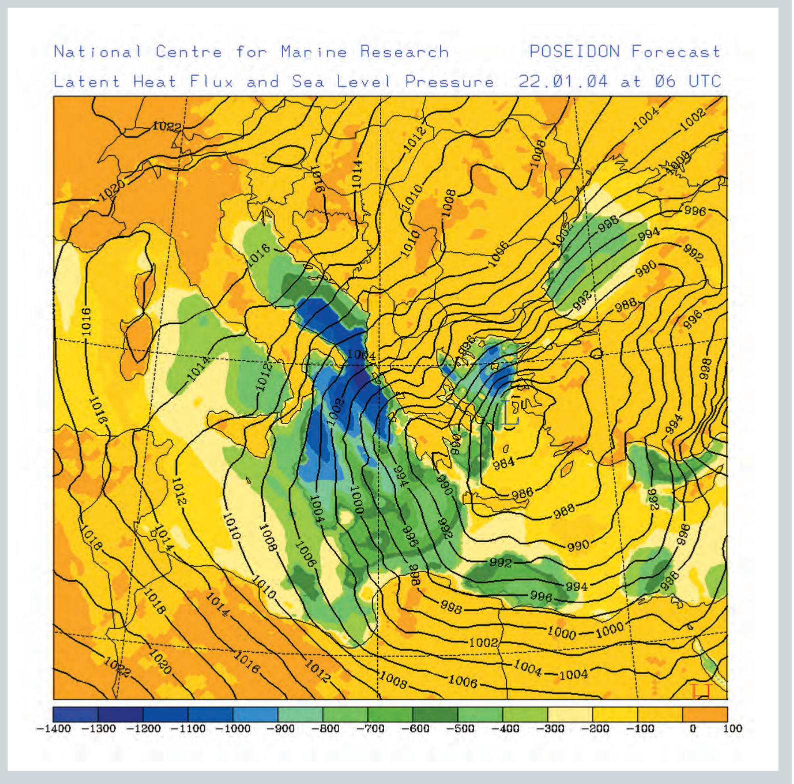


Figure II.2:
Model estimated latent heat flux that provides the energy supply to intensify the cyclone on 22 January 2004.

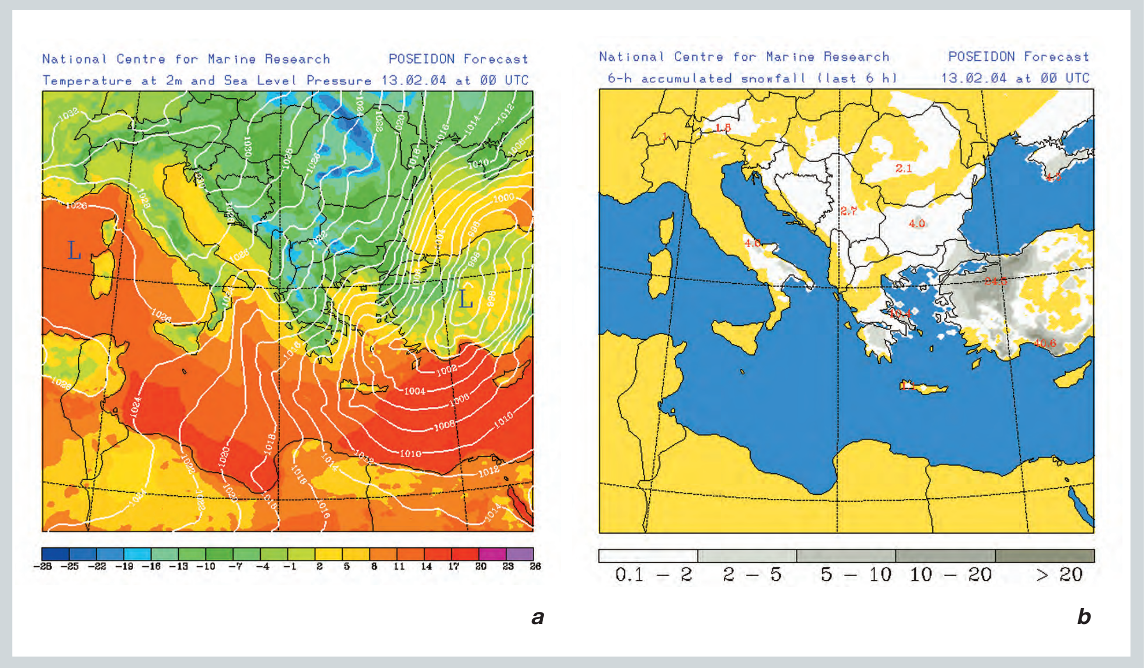
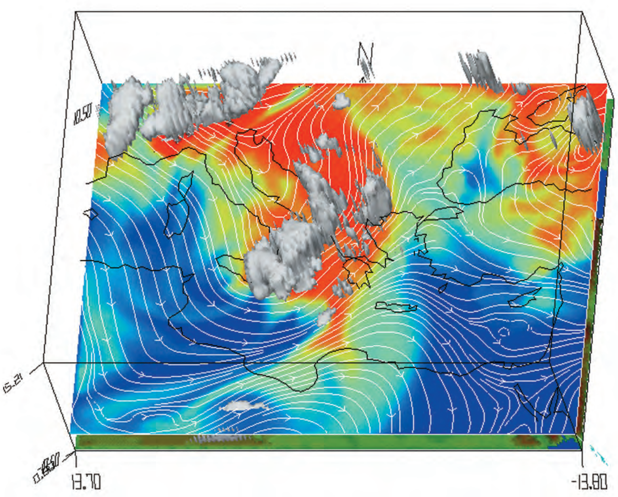


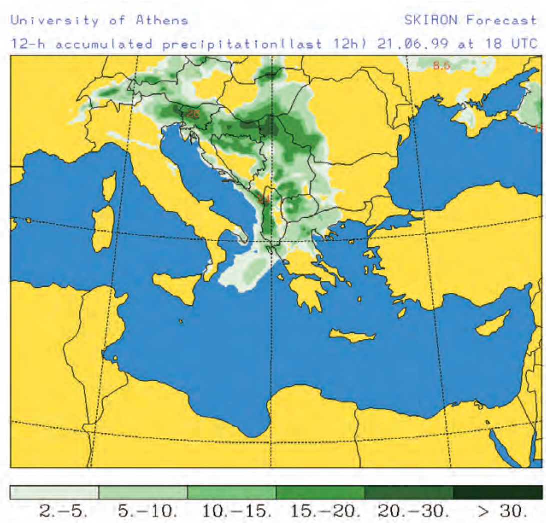
Figure II.3:
POSEIDON forecasts of (a) air temperature and mean sea level pressure and (b) 6-hourly accumulated snowfall (in cm) at 00 UTC on 13 February 2004.

Asian monsoonal effect as they are produced due to the development of the intense heat trough over southern Asia that extends westwards over the Anatolian Plateau and the high pressure dominates over the Balkan Peninsula. The interaction between these two systems affects the strength of the Etesian winds, even their existence. When the thermal lows over Turkey deepen enough and the high-pressure system weakens, a strong pressure gradient over the Dardanelles and the Aegean is forming during the day that weakens at night. During these days, strong northerly winds persist across the Aegean and all the way to the North African coast. During a strong Etesian, the trough may extend relatively far to the west and beyond Rodos. It may also form a closed low, resulting in almost calm winds at Rodos Island. When the high-pressure system is strengthening against the thermal low, a weak northern flow prevails across the Aegean Sea. In these cases, the local thermal circulations dominate the region. Sea breeze systems are frequently in evidence in coastal regions. Sea breezes blow in the afternoon until near sunset when they become calm, while land breezes are light winds and blow in the early morning.

THE TRANSIENT PERIOD

This period of the year is characterised by the interchange of the winter- and summer-type weather patterns. The transition from winter to summer lasts about three months (from March to May). The approach of spring is indicated by the incipient decay of the Siberian anticyclone. When the winter anticyclone collapses it ceases to bring cold air and warm weather establishes in the





Source: *PAPADOPOULOS, 2001.*

Figure II.4: *Model simulated atmospheric conditions leading to the convective rainstorm occuring on 21 June 1999. Left panel shows the vertical wind speed exceeding 3 m/s (white areas), the streamlines of the horizontal wind at 2 500 m, and the relative humidity at the same elevation indicating by the colour scale areas with the red scale areas presenting values exceeding 80%. Right panel shows the simulated 12-hourly accumulated precipitation.*

eastern Mediterranean. The cyclonic activity becomes less frequent and less intense as summer approaches. The cyclogenesis in North Africa becomes the primary cyclogenesis centre, resulting in southerly winds bringing to the region significant amounts of Saharan desert dust (Figure II.5). The strong winter northerly winds become weaker and the Etesian winds have not yet developed. Despite the fact that the summer-like weather conditions become more frequent as summer approaches, winter-type cyclones may still appear even until late May.

Autumn lasts only about one month (October) and is characterised by a fairly decisive change from summer to winter regime. The winter activity in the cyclogenesis centres increases and the first cyclone may appear by the end of the month. During autumn, heavy rains usually occur because of the strong contrast between the temperature of the surface waters of the eastern Mediterranean Sea and the overlying continental air masses that cause strong evaporation.

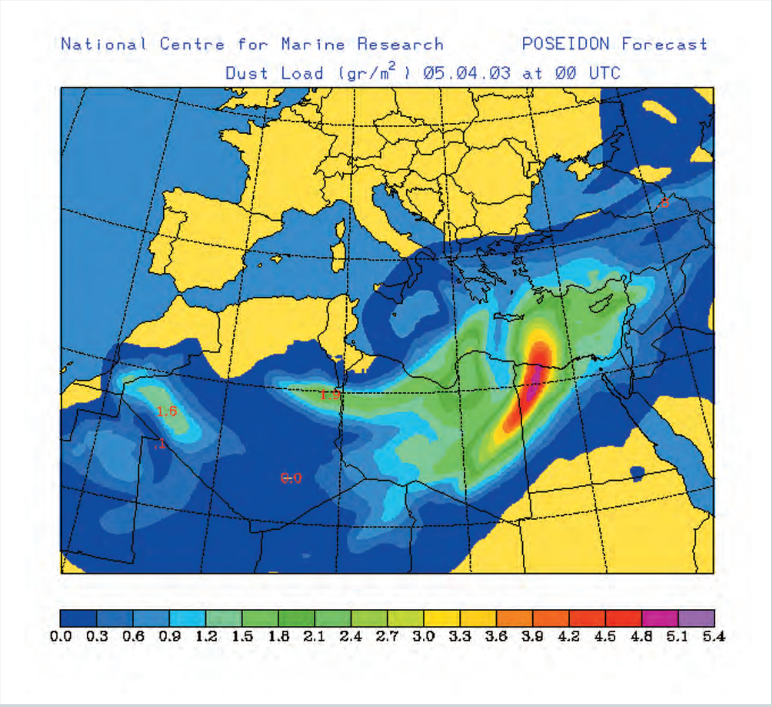


Figure II.5:
POSEIDON forecasts for the dust load at 00 UTC on 5 April 2003.

II.2. AIR-SEA EXCHANGES

Mean weather conditions described in the previous section permit the calculation of the climatology of air-sea fluxes. These include exchanges of heat, freshwater and momentum, which largely determine the oceanic circulation, water mass formation as well as the hydrological cycle of the region.

Why do we measure air-sea fluxes?

The amount of heat flux entering the ocean is a major component of the ocean-atmosphere interaction and determines the oceanic and biogeochemichal processes in the eastern Mediterranean in various time scales. However, the heat flux into the ocean is the result of several complicated processes including the influence of clouds, aerosols, water vapour or greenhouse gases as well as the condition and characteristics of the ocean surface. Such processes are differentiated and modified by the enclosed nature of the Mediterranean geomorphology, so that the air-sea heat exchanges in this area require dedicated consideration.

The freshwater exchanges also play a key role in the hydrological cycle of the eastern Mediterranean, a sensitive component of the regional climate. The Mediterranean Sea is, in general, an important source of moisture for the atmosphere. Therefore, the components of the local water budget not only influence the sea circulation and water quality, but also define the amount of moisture available for the surrounding countries. In particular, the southern part of the basin is quite arid, due to the specific climatological characteristics of the regional evaporation and precipitation. This implies that any variability in the components of the hydrological cycle may result in important socio-economic consequences.

How do we measure air-sea fluxes?

At present there are several methods of estimating the air-sea heat and freshwater fluxes: (i) direct measurements are extremely scarce and sporadic in the eastern Mediterranean and the Hellenic seas to contribute directly to the calculation of large-scale flux fields, (ii) satellite observations provide global coverage but for a limited range of variables, (iii) model results assimilate the various information available and produce regular gridded fields of fluxes, and (iv) bulk formulas in conjunction with long-term marine meteorological and hydrographic observations are still useful because of their duration and global coverage.

The semi-enclosed nature of the Mediterranean Sea provides an invaluable tool to test the validity of the air-sea exchange estimates of the above measurements. This involves the comparison of the surface heat and freshwater budget with the well known advective heat and freshwater fluxes through the Straits of Gibraltar (GARRETT *et al.*, 1993). Such a constraint is not readily available for the eastern Mediterranean, though, as the Strait of Sicily is a more complex system of inflow-outflow, which makes measurements of the buoyancy budget there less trustworthy. Therefore, the estimates for the air-sea exchanges presented here cover the whole Mediterranean and are tested for their agreement with the buoyancy budget at the Straits of Gibraltar.

Such estimates come from the dataset of DA SILVA *et al.*, in 1994 (hereafter UWM/COADS), which includes evaluations from bulk formulas for a period of 49 years (1945-1993), corrected to comply with the heat and freshwater exchanges at the Straits of Gibraltar. Estimates from this data set will be used to present a picture of the air-sea exchanges in the eastern Mediterranean. Although systematic errors exist, these data provide an idea of the spatial and temporal variations in the region.

In this section we focus on the climatology of the air-sea heat and freshwater fluxes. However, this picture is altered by significant interannual variations, which are likely to be responsible for remarkable variations in the functioning of the eastern Mediterranean system, discussed in Chapter III.

CLIMATOLOGICAL MEAN SURFACE HEAT AND FRESHWATER FLUXES

The long-term mean climatological fields for surface heat and freshwater fluxes in the Mediterranean are shown in Figures II.6 and II.7 . The spatial variation of the data fields presented here is consistent with previous climatological studies such as JOSEY (2003). A quantitative description of the contribution of each sub-basin to the total heat is given in Table II.1, where indicative values of the freshwater and buoyancy budgets of the Mediterranean and its sub-basins are presented, derived from the constrained UWM/COADS. The Levantine basin is defined eastward of 25˚E and the Ionian basin is west of 25˚E, up to 40˚N. The typical north-south gradient in the heat flux appears to be superimposed to an east-west variation. Overall, the eastern basin loses less heat than its western counterpart, whereas the freshwater deficit is stronger in the eastern basin. The eastern Mediterranean and the Levantine Sea undergo the strongest evaporative losses (of about 0.89 m y^{-1}), although the latter is a region of net heat gain. Heat is also gained by the Ionian Sea, which indicates that the overall heat loss in the eastern Mediterranean is due to the strong heat losses of the significantly smaller Aegean and Adriatic seas. The Aegean Sea experiences the most intense heat and freshwater losses leading to the highest surface buoyancy loss in the Mediterranean; higher than the buoyancy loss of the Adriatic Sea which has been traditionally considered the deep-water formation site for the eastern Mediterranean. However, as will be shown later, the net buoyancy budget of the Aegean and its thermohaline circulation are strongly influenced by the inflow of Black Sea water.

Overall, the eastern Mediterranean Sea loses buoyancy through the atmosphere, which implies that on an annual basis more buoyant water has to enter the basin through the Strait of Sicily to preserve the characteristics of the basin; the role of the Suez Canal is considered negligible. The spatial and temporal variability of the heat and freshwater fluxes will be discussed in the following sections.

Heat fluxes in the Eastern Mediterranean

A possible explanation for the spatial distribution of the heat fluxes in the Mediterranean (Figure II.6) comes from the examination of the different components and the associated meteorological parameters.

The short-wave radiation is the largest component (of the order of 180 Wm^{-2}), mainly responsible for the north-south gradient, which is modified by the presence of clouds, ozone, CO_2, water vapour and aerosols that attenuate the incoming solar radiation. Recent research has shown that aerosols play a significant role in the solar radiation fields over the Mediterranean and the Hellenic Seas in particular, due to their geographic location and the regional weather systems, resulting in a reduction of the solar radiation close to 30 Wm^{-2}. High aerosol concentration is observed in the Ionian and the Aegean seas that exhibits strong seasonal and interannual variability (TRAGOU & LASCARATOS, 2003) depending on the prevailing weather conditions; strong winds and precipitation rapidly remove aerosols from the atmosphere, while in calm weather conditions they accumulate over the basin resulting in a persistent haze. It is likely that natural aerosols (Saharan dust) mostly affect the solar radiation over the Ionian Sea and the Levantine basin (e.g. Figure II.5), while in the Aegean Sea aerosols are possibly of anthropogenic urban origin.

Strong heat loss patterns in the eastern Mediterranean and the Aegean Sea are primarily

Table II.1: *Heat and freshwater budgets of the Mediterranean Sea and sub-basins derived from the constrained UWM/COADS. Positive buoyancy fluxes indicate net buoyancy loss to the atmosphere.*

	Heat flux ($W m^{-2}$)	Freshwater flux (E-P) ($m y^{-1}$)	Buoyancy flux ($kg m^{-1} s^{-3}$) × 10^{-5}
Mediterranean Sea	-5	0.69	0.30
Western Mediterranean	-8	0.55	0.47
Eastern Mediterranean	-4	0.76	0.24
Ionian Sea	+2	0.69	-0.12
Levantine Sea	+1	0.89	-0.06
Aegean Sea	-29	0.94	1.71
Adriatic Sea	-28	0.43	1.65

due to the high latent heat flux component, which is particularly strong in the central part of the eastern basin. The enhanced latent heat flux in this region arises from the advection of cold dry air from eastern Europe (as described in the previous section for the prevailing weather systems) that in turn sets up a large air-sea humidity gradient that enables strong evaporative losses. The overall evaporative losses in the Mediterranean are of the order of 100 Wm^{-2}, which is enhanced in the eastern basin.

For the long-wave radiation, little is known in the eastern Mediterranean as most estimates either come from radiative transfer models or from algorithms that have been extracted based on marine measurements in other oceanic environments, which hardly resemble the eastern Mediterranean properties of clouds, cloud height and water vapour pressure. For the whole Mediterranean the heat lost by long-wave radiation is of the order of 70 Wm^{-2}. Finally, a relatively small contribution to the total heat flux comes from the sensible heat loss, which is of the order of 10 Wm^{-2}.

The climatological seasonal cycle of the heat fluxes in the sub basins of the eastern Mediterranean is presented in Figure II.8. Seasonality appears to be quite similar in all four sub-basins with maximum values up to 200 Wm^{-2} gain in the summer and heat loss of the same order in the winter.

Freshwater fluxes in the Eastern Mediterranean Sea

In the Mediterranean evaporation is the largest term of the freshwater budget, therefore, the evaporation minus precipitation field is controlled mostly by evaporation; precipitation is relatively weak over the whole basin and about half the evaporation. Throughout the year the Mediterranean has a freshwater deficit, which, depending on the data source, ranges from 0.5 to 0.9 m y^{-1} (MARIOTTI *et al.*, 2002). In the case of the UWM/COADS the Mediterranean mean E-P rate corresponds to about 0.7 m y^{-1}, with highest rates observed in the Aegean and the Levantine seas and minimum in the Adriatic (Figure II.7 and Table II.1). The climatological seasonal cycle of the E-P rate in the sub-basins of the eastern Mediterranean is presented in Figure II.8. Maximum values are observed in the autumn and minimum in the spring. The Adriatic seasonal cycle is altered by its weaker evaporation rates and appears to be the only sub-basin with negative E-P rates in the spring.

The evaporation rate in the Mediterranean is stronger during winter, primarily because of the stronger winds and drier atmospheric conditions as described in the previous section about the weather systems. Winter evaporation rates exceed 1.5 m y^{-1} in the Aegean, the Levantine and part of the Ionian seas. Summer evaporation rates are smaller by about 0.4 m y^{-1} throughout the eastern Mediterranean region, and gradually increasing towards the Balkan Peninsula. The climatological seasonal cycle of the area-averaged evaporation over the whole Mediterranean shows maximum evaporation rates in autumn-winter (from October to January) and minimum in spring (from April to June).

In all seasons the latitudinal gradient is the predominant feature of precipitation. Drier areas

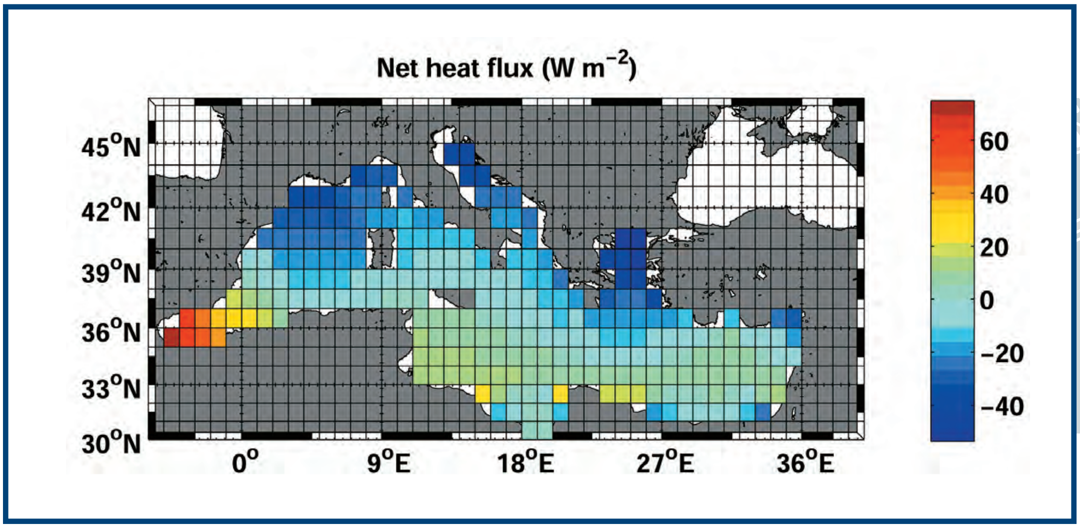


Figure II.6: *Net heat flux climatology derived from the constrained UWM/COADS, adjusted to have an average value of -5Wm^{-2} for the whole Mediterranean.*

are observed along the African coast and significantly wetter ones close to the European coast. Various datasets analysed by MARIOTTI *et al.,* (2002) indicate that on average the eastern Mediterranean tends to be wetter in the winter than the western basin. Maximum precipitation is observed in the winter in the Ionian coast of Hellas (over 0.75 m y^{-1}) and the southern coast of Turkey. In the summer the eastern Mediterranean is very dry south of 40˚N with precipitation rates less than 0.2 m y^{-1}. The climatological seasonal cycle of the area-averaged precipitation rate over the whole Mediterranean shows an extended rainy season from autumn to spring with maximum rates in November to January and minimum from June to August.

Figure II.7: *Freshwater flux in the Mediterranean Sea from the constrained data of UWM/COADS. Positive values are freshwater loss.*

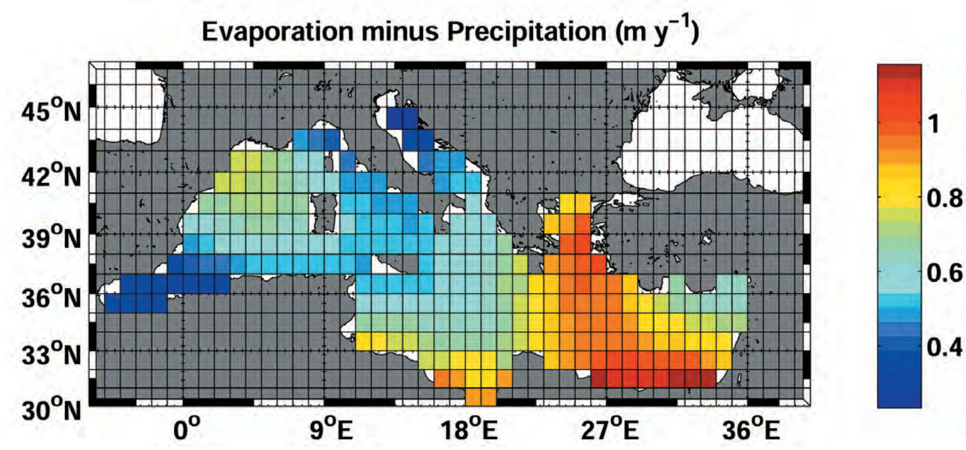
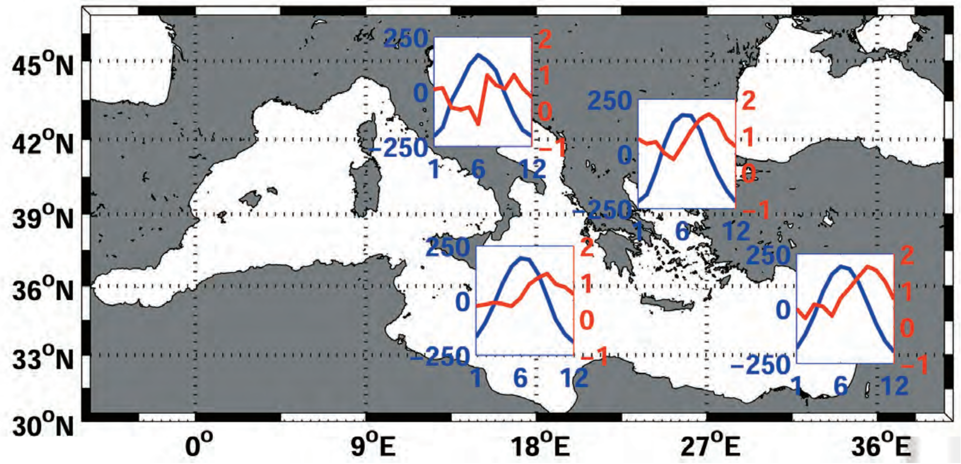


Figure II.8: *Climatological seasonal cycle of the area-averaged heat and freshwater fluxes, derived from the constrained UWM/COADS, in the four eastern Mediterranean sub-basins. Heat fluxes are plotted in blue and their values correspond to the left-hand axes, while freshwater fluxes are plotted in red and correspond to the right-hand axes.*



II.3. THE WAVE CLIMATE OF THE AEGEAN SEA: WIND WAVES

INTRODUCTION

The generation and propagation of sea surface waves is one of the most amazing and complex phenomena taking place in the sea environment. The knowledge of the wave behaviour in short and long-term time scales is important for a diverse field of marine applications and operations. Wave measurement was for a long period of time a rather difficult technical (and theoretical) task. Nowadays, quantitative information about wind waves can be obtained by a variety of ways. Real time wave measurements are critical for sea navigation, for marine operational activities, optimal ship routing and improvement of the forecasts obtained from numerical wave models.

The exact physical mechanisms of wind wave generation, development and decaying are still not exactly known. It is generally accepted that in the initial phase of wave generation, the fluctuations of the atmospheric pressure induces very small amplitude waves called capillary waves. As the wind continues to blow and wind speed increases, waves get larger (develop) while gravity forces support the wave motion. Wave growth is finite: when waves reach the limiting steepness they break (in the form of white caps or plunging or spilling breakers). A number of studies (see HASSELMANN (1968 and references therein) laid the basis for modern wind wave modelling. A general review on sea waves can be found in LeBLOND & MYSAK (1978) while the state of the art in wind wave dynamics is described in LAVRENOV (2003).

Long-term accumulated wave data provide a basis for wave climate analysis in local, regional and global space scales. Wave climate analysis deals mainly with the long-term statistical behaviour of the most important wave parameters as, for example, significant wave height and wave period and their evolution in the space and long-term time scales. Coastal and offshore engineering applications dealing with the design of breakwaters and other coastal defence works, the design and safety of offshore structures (oil and gas production platforms) and exploitation of wave power are only some of the fields where accumulated local wave information is invaluable. Long-term wave data can be also obtained through wave hindcasting, a numerical process that is described in the section after the following.

WAVE DATA FOR THE HELLENIC SEAS

Concerning the Hellenic Seas the sources of wave data are:

a) *in-situ* measurements using wave buoys,
b) satellite altimetry products,
c) visual observations,
d) wave model hindcasts.

The Hellenic Centre for Marine Research (HCMR) has established a systematic wave measurement programme within the framework of the POSEIDON project (SOUKISSIAN *et al.*, 1999). Wave measurements are made by means of 10 floating oceanographic stations equipped with an MRU (Motion Reference Unit) wave directional sensor. The recording period of the measurements is 1024 sec and the recording interval is 3 hours. The current buoy locations are shown in Figure II.9. The main measured wave parameters obtained from the directional spectral density function are the significant wave height, the mean zero up-crossing period and the main wave direction.

Satellite altimetry products include wave measurements obtained from Topex / Poseidon (T/P for brevity), which are further producing the Merged Geophysical Data Records (GDR-M) processed and provided by AVISO, AVISO/ Altimetry (1996). These data are the merged GDR products of the two sensors designed to be used in ocean and geophysical studies. They have been both calibrated and corrected for all instrumental errors, and various flags have been applied setting checks for gaps, exceeding limits and extensive changes.

Additional calibration corrections have been made to Poseidon data so that it would be possible to produce homogeneous data with Topex, and thus allowing the user not to have to distinguish the one sensor from the other, AVISO/Altimetry (1996).

T/P covers the Hellenic Seas by six tracks and corresponding wave data are available since 1993 with 10 days sampling interval. Some known problems related with T/P products, except for the rather extended sampling interval, refer to the footprint size of the satellite (the beam illuminates a circle of ocean 3 to 5 km wide, depending on the sea-state intensity) and the inability of the satellite to measure sea level in the presence of land within its footprint. Practically, this means that all sea areas within 3 to 5 kilometres of continental coasts or islands are not covered.

Visual observations were the basic source of wave data for at least a century. Visual wave data include observations of visual wave height H_V, visual wave period T_V and visual wave direction Θ_V, made by trained personnel on board Voluntary Observing Ships. Visual wave data over the past 100 years have been collected, processed and stored in the data banks of various Meteorological Offices. The specific data for the Hellenic Seas are available from the Meteorological Office, England in a resolution of 1° x 1° and have been published in the form of a Wave/Wind Atlas, ATHANASSOULIS & SKARSOULIS (1992).

WAVE FORECASTING AND HINDCAST DATA

The prediction of wave characteristics is another issue of equal or even superior importance compared to wave measurements, in many applications. Reliable wave forecasts are necessary for navigation and safety of life at sea, search and rescue missions, ship responses to waves (especially pitching and rolling), optimal ship routing, etc.

Modern development of wave forecasting has been initiated during the Second World War, since the sea-state forecast was required for amphibious landing operations. The first **empirical** method for the operational forecast of wave parameters was introduced by SVERDRUP & MUNK (1947), who also introduced a parametric description of the sea state. Using empirical data BRETSCHNEIDER (1958, 1970) revised the above method, subsequently called the Sverdrup-Munk-Bretshneider (SMB) method. A detailed review of the development of wave modelling until the mid 1990's is presented in SWAMP (1985). An international collaboration between scientists from different countries in the years from 1984 to 1989, resulted in the establishment of a third-generation wave model called the WAve Model. An analytical description of the WAM model can be found in KOMEN *et al.*, 1994.

Numerical wave models can also be used for accumulating long-term wave data in both space and time scales using wave hindcasting. It consists of the implementation of numerical wave models using as input historic wind fields. The obtained wave data are called hindcast data.

Figure II.9: *Wave measurement locations in the Aegean Sea.*

WAVE FORECASTING IN HELLAS

Operational wave forecasts are produced by the Hydrographical Service of the Hellenic Navy using a classical empirical SMB model. Since 1998 HCMR provides daily wave forecasts for the Aegean and east Ionian Sea on the Internet (www.poseidon.ncmr.gr) using as basic model DAUT, the operational version of a second-generation wave model developed at the Aristotle University of Thessaloniki CHRISTOPOULOS & KOUTITAS (1991). Since 1999 HCMR uses, in parallel with the DAUT model, the WAM-cycle 4 model in forecasting mode. Intercomparisons of WAM and other wave models (DAUT and MIKE 21), as well as comparisons of their results with buoy measurements and satellite data for the Aegean Sea, can be found in SOUKISSIAN *et al.*, (2001) and KECHRIS, & SOUKISSIAN (2004). For the wave simulation in the coastal zone HCMR uses the SWAN wave model developed at the Delft Technical University, BOOIJ *et al.*, (1999). SWAN is a refraction model specifically developed for simulating wave conditions near-shore and takes into account the refraction and shoaling due to bottom and current variations, blocking and reflections by opposing currents, transmission through or blockage by sub-grid obstacles and dissipation by bottom friction and depth-induced wave breaking. An operational nested version of the SWAN model (in an analysis of 1/120˚) within the WAM model has been used during the Athens Olympic Games 2004 for the sea-state forecast in the area of sailing competitions in the Saronikos Gulf, SOUKISSIAN (2004). The WAM model is also operated by the Hellenic National Meteorological Service using wind fields obtained from the European Centre for Medium-Weather Forecasting (**ECMWF**), but without evaluating or publishing relative results.

In the implementation of the WAM model used in HCMR, WAM is fed by the wind fields from a weather forecasting model based on the SKIRON system, which has been developed by the University of Athens, KALLOS *et al.*, (1997). The meteorological model runs in two cycles per day: i) the coarse one (resolution 0.24˚ or about 23 km) with area of application 24.2˚W–51.8˚E and 12.9˚N–53.4˚N and initial and boundary conditions obtained from the US National Centre for Environmental Prediction (NCEP); ii) the results of this version are interpolated to a finer grid (resolution 0.10˚ or about 10 km) with area of application 2.6˚E–38.4˚E and 27.4˚N–49.5˚N. WAM is also performed in two steps: i) the whole Mediterranean (5.75˚W–36.25˚E, 30.25˚N–46˚N) with resolution 0.25˚, and ii) the Aegean (20˚E–29˚E, 34˚N–41˚N) with resolution 0.05˚, using as boundary conditions the results of the Mediterranean version. The propagation time step is 720 sec for the Mediterranean version and 180 sec for the Aegean one. For both cases 24 discrete directions are considered, and the estimation of spectral density is performed within the range 0.05054 – 0.66264 Hz, which is discretised logarithmically in 28 discrete frequencies.

Apart from operational wave forecasts, hindcast wave data from various sources are also available for the Hellenic Seas: Ten-year coarse hindcast wave data for the Mediterranean Sea produced by the Spectral Ocean Wave Model (**SOWM**), a second-generation deep water model, are available in the form of time-series and frequency tables from the US National Climatic Data Centre, US NAVY (1989). The Atlas contains summaries for wind speed and direction, significant wave height, wave direction, wave slope, modal wave period and wave directionality. Monthly and annual data are presented in various forms (isopleths, contingency tables and duration-interval tables). In the framework of the MAST-3 programme 'EUROWAVES' (BARSTOW *et al.*, 2000), six-year hindcast wave data were produced for the Aegean Sea (in a 0.5˚ x 0.5˚ grid) using WAM and ECMWF wind fields, and compared with satellite data. In a current project of HCMR (2003-2006), funded by the Greek General Secretariat of Research and Technology, ten-year hindcast wave data will be produced for the Aegean Sea by using ECMWF wind fields and the WAM wave model. These data will be available in the form of a Wave and Wind Atlas for the Hellenic Seas, SOUKISSIAN (2003).

RESULTS FOR THE AEGEAN SEA

A main feature of the WAM model results obtained for the Aegean Sea is the underestimation of the high values of significant wave height H_S. The relative errors for the mean wave period T_Z are generally smaller compared to those of H_S. Further statistical analysis reveals that WAM overestimates, in general, the small H_S values ($0.25 \le H_S \le 1$) and underestimates the higher ones ($H_S > 1$). On the contrary, WAM describes satisfactorily the sea-state evolution pattern in both time and space scales, though deviations of smaller or greater magnitude (dependent significantly on the location of the wave measurements) are also present.

Defining the relative error by the simple relation:

$$RE = \frac{H_{S,BUOY} - H_{S,WAM}}{H_{S,BUOY}},$$

a statistical analysis of wave data at four measuring locations (Santorini 36.15˚ N - 25.30˚ E, Lesvos 39.09˚ N - 25.48˚ E, Athos 39.96˚ N - 24.72˚ E and Mykonos 37.30˚ N - 25.27˚ E), indicates that the mean monthly values of significant wave height RE ranges from 0.19 to 0.50 and for the mean wave period from -0.01 to -0.11. The detailed evaluation of the WAM model results using *in-situ* wave measurements can be found in SOUKISSIAN & PROSPATHOPOULOS (2003). In the same work a statistical analysis of the mean monthly wind speed obtained from measurements and wind model results revealed that *RE* ranges from -0.02 to 0.41. A comparison of buoy and T/P measurements is presented in KECHRIS & SOUKISSIAN (2004).

In Figure II.10 the sorted time series of buoy measurements along with WAM model results are plotted for the Athos station. In this figure, the underestimation trend of the WAM model for the higher values of H_S is clearly shown.

In Figure II.11 the spatial distribution of the mean monthly significant wave height obtained from WAM, after four years of forecasting operation (1999-2003), is presented for the entire Aegean Sea. To start with, let us first note that on average, the dominant winds over the Aegean blow from the north. Second in frequency are the southern winds, whereas the eastern and western winds have much lower frequencies of occurrence. During the summer period, the Etesians, a large-scale open-sea wind system, blow from the north and their effect in wave propagation is evident, especially during July and August. The Etesians have an axis of maximum wind force running cyclonically from the Dardanelles, through the Kyklades, past Karpathos Island and on towards the centre of the eastern Levantine. The behaviour of this wind system makes the wave propagation patterns in the Aegean Sea complicated. In late autumn, the Etesians diminish and the Aegean Sea comes under the influence of violent cyclonic storms.

Regarding the prevailing wave conditions during June, July and August, the wave patterns are clearly shaped by the Etesians. The most intense wave action takes place in the southeastern Aegean (just outside the straits of Kasos–Kriti and Rodos-Karpathos) strengthened by the channelling effect. During August, high sea states are also observed in the central Aegean, north of the Kyklades complex. Calm wave conditions prevail during May, mainly September and October. October is apparently a transitional month, since from November until February the wave conditions become increasingly intense, mainly in the southeastern, southwestern and upper central Aegean. During these months the prevailing wave patterns are of identical form, which is also true for March, but with clearly lower intensity. It is evident that on a mean annual basis, the overall most intense wave conditions prevail at the Kasos–Kriti and Kythira–Kriti straits. Finally, the spreading and dissipation of the wave energy at the Kyklades complex renders these islands an area of relatively mild wave conditions.

The spatial distribution of the significant wave height and wind speed on a mean annual basis is presented in Figure II.12.

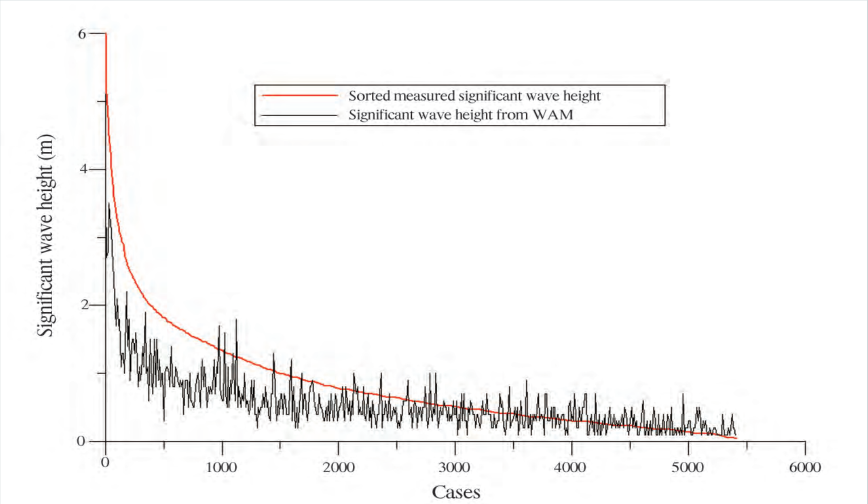


Figure II.10:
Sorted significant wave height as obtained from buoy measurements and WAM model results at Athos Station.

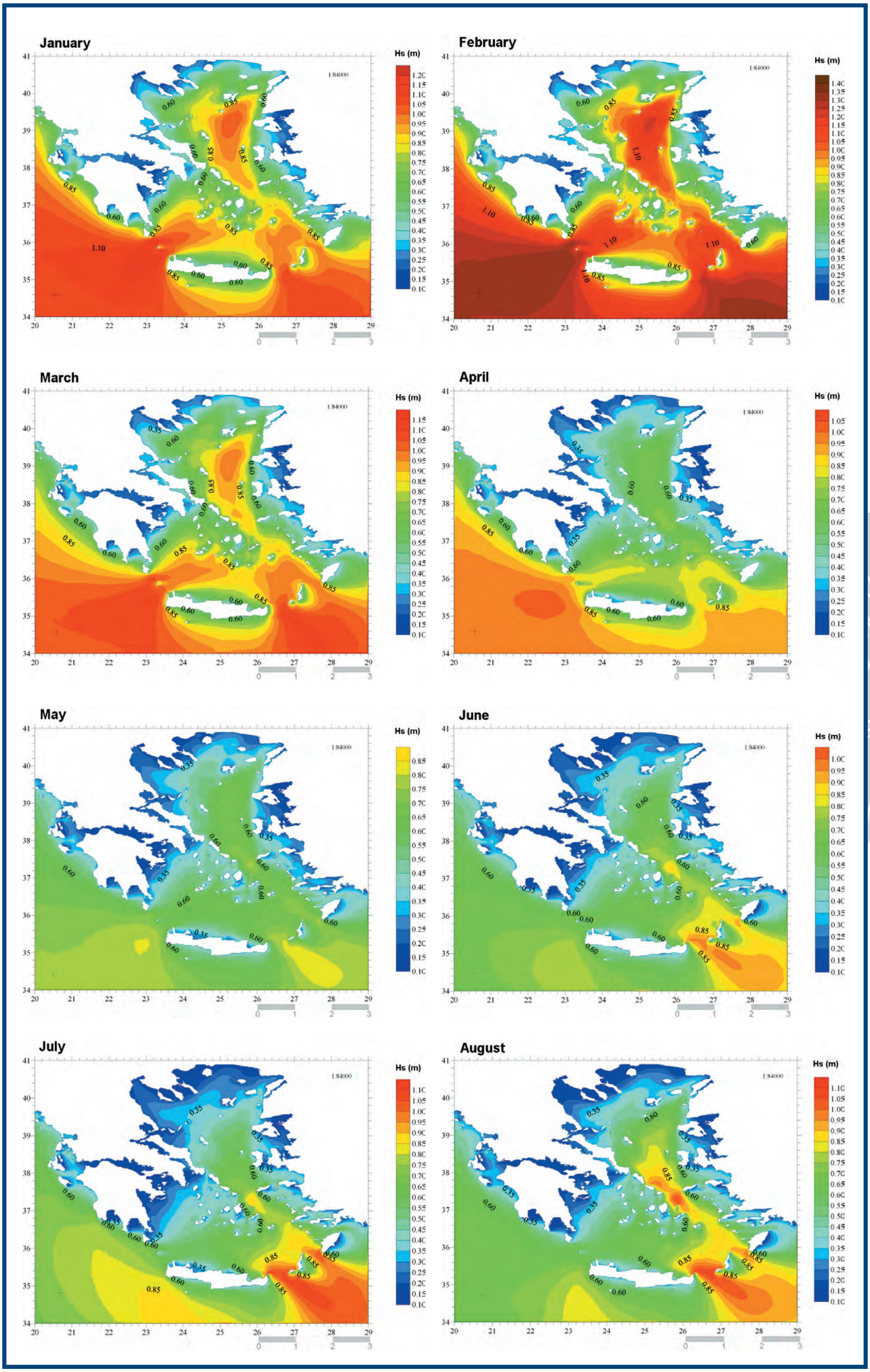


Figure II.11: *Mean monthly significant wave height spatial distribution in the Hellenic Seas. The colour scale denotes significant wave height in (m). (continued)*

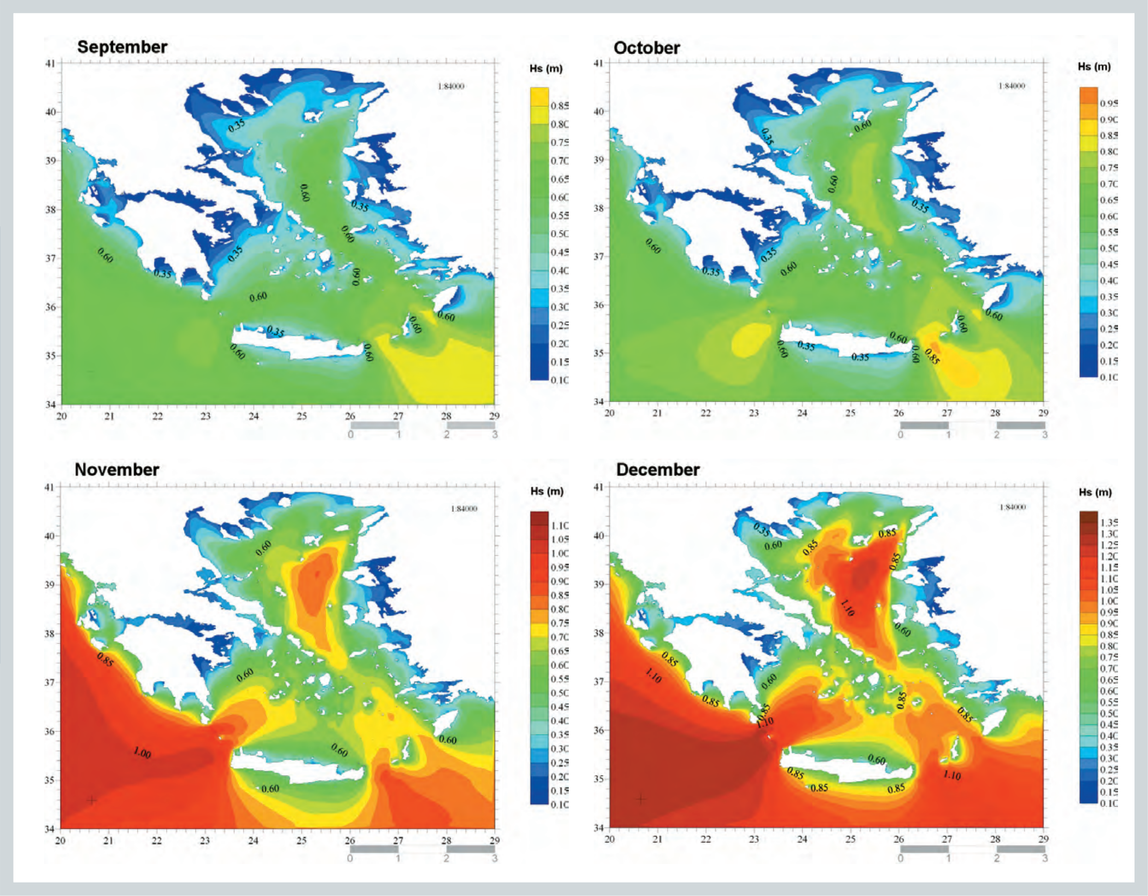


Figure II.11: *(continued) Mean monthly significant wave height spatial distribution in the Hellenic Seas. The colour scale denotes significant wave height in (m).*

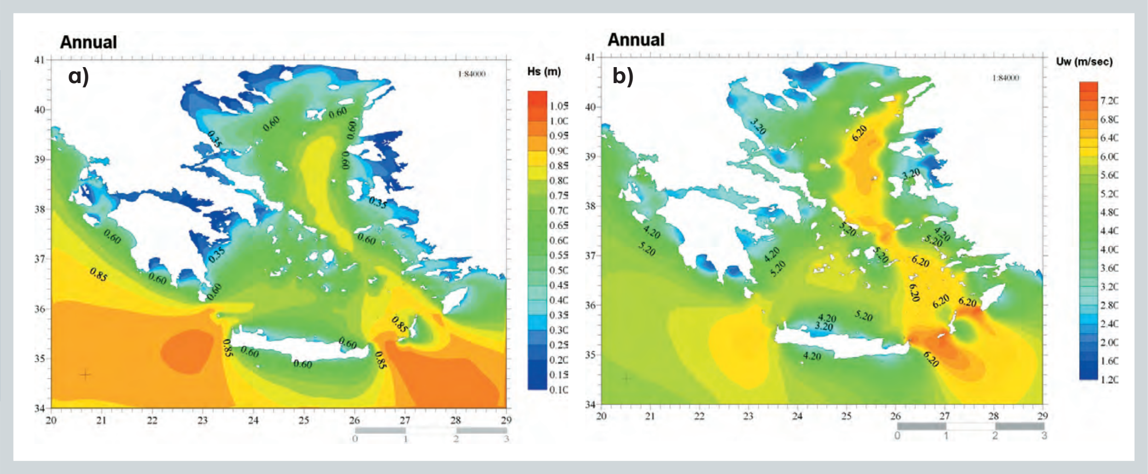


Figure II.12: *Mean annual spatial distribution of a) wave height (m), b) wind speed (m/sec).*

II.4. THE WAVE CLIMATE OF THE AEGEAN SEA: THE TIDAL SIGNAL

The tidal wave is produced by the differential attraction of the water masses by the astronomic bodies, mainly the moon and the sun. Thus, it is usually described by a combination of harmonics and sub-harmonics that are astronomically determined. The tidal harmonics cluster within specific frequency bands, the most important of which are those with periods around 12 hours (the semi-diurnal band) and those with periods around 24 hours (the diurnal band)) At a particular location, resonance due to bathymetric and coastal features can generate, reinforce or dampen particular harmonics. The harmonic analysis of relatively short sea level records (i.e. 1 month -1 year) usually gives us enough information to predict the tide at a particular location with good accuracy for all practical purposes. Thus, tides have long been considered as well understood, a view not supported when the internal tides or the dissipation of energy of the tidal signal are concerned. The tidal oscillations at sea level are accompanied by currents of similar frequencies. The understanding of the tidal currents is of importance in respect of navigation, the spreading of pollutants, coastal geomorphology, the movement of sediments, the deployment of underwater instruments and the construction of offshore structures.

The tidal signal in the Aegean and the Ionian seas is part of the Mediterranean tidal regime and cannot be described or understood in isolation. The tide of the Mediterranean is of the order of centimetres and for this reason has not been studied as intensively as in other parts of the world where its knowledge is crucial for navigational and coastal protection purposes. However, the interest in the accurate determination of the tidal signal in the area has been revitalised during the last decade in the context of climate change, as it is important for the optimum use of satellite altimetry and the need to provide precise tidal loading estimations for GPS stations in the region.

THE FORCING OF THE TIDES IN THE EASTERN MEDITERRANEAN

The tides of the Mediterranean are produced by the interaction between the direct action of the local astronomic forcing together with the part of the Atlantic tidal wave that can penetrate through the Straits of Gibraltar. This produces tidal components which exceed values of 10 cm only in certain areas within the Mediterranean namely, the north Aegean Sea, the Adriatic Sea and the Gulf of Gabes. Enhanced tidal currents, known since antiquity, are produced in the Messina Strait, between the Italian peninsula and Sicily, and in the Evripos Strait between mainland Hellas and the island of Evvoia.

A high resolution numerical model (TSIMPLIS *et al.*, 1995) which compares the existing tidal signal with the signal produced when the Straits of Gibraltar are considered (in the model) as closed, indicates that the observed tidal signal in the Mediterranean is significantly influenced by the incoming tide. In particular, in the northern Aegean Sea, where a basin oscillation at the semi-diurnal period exists, the effect of the incoming tidal wave is to reduce the tidal amplitude of the semi-diurnal tides by about 50%.

THE PROPAGATION OF THE TIDAL SIGNAL IN THE SEAS SURROUNDING HELLAS

The major tidal component in the Aegean, the Ionian and the Levantine seas is the semi-diurnal component M_2. The estimates of amplitude and phase of M_2 from a numerical model (TSIMPLIS *et al.*, 1995) can be seen in Figure II.13. The estimates for harmonics at particular tide gauges are also shown (TSIMPLIS, 1994). The highest amplitudes can be found on the north coasts of the Aegean and in the semi-enclosed basins of the north

Evvoikos Gulf and Korinthiakos Gulf. Notably there are discrepancies in some of the values of the harmonic derived from direct measurements. Although the direct measurements are the most reliable source for local information they remain representative of the particular location, which can be subject to particular topographical features within the port or nearby river. Thus, care should be taken when these are used to derive estimates for the open water. Local topographic enhancement is responsible for the enhancement of the tidal signal in the north Evvoikos Gulf and the Korinthiakos Gulf (Fig. II.13).

The total tidal range defined through the model as the addition of the four major components M_2, S_2, K_1 and O_1, is shown in Figure II.14. The tidal range is less than 0.5 m with highest values in the north Aegean and the semi-enclosed gulfs.

The true tidal range can only be determined from local sea level measurements. Around 20 tide gauges have been intermittently in operation at the coasts of Hellas. The operating authority is the Hydrographic Service of the Hellenic Navy but other entities have occasionally established instruments for research or environmental assessment purposes. Harmonic analyses for segments of these data are available and these should be consulted for accurate estimates of the tidal range. For example, in the north Aegean the MA_2 and MB_2, generated by interaction of the M_2 with the local

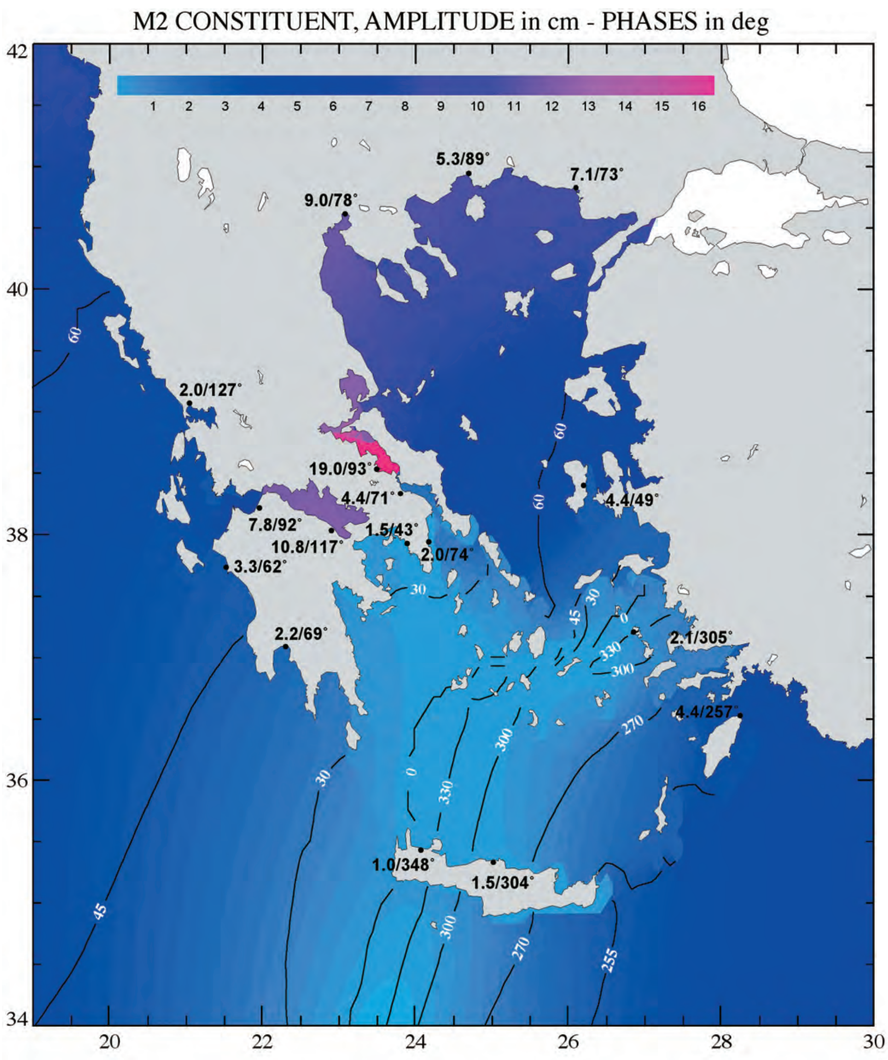


Figure II.13:
The M_2 tidal component in the Hellenic Seas from the tidal model of TSIMPLIS et al., (1995). The amplitude is colour coded while the phases (GMT) are shown as continuous lines. The measured amplitudes and phases from tide gauge measurements are also shown.

Source: *Based on TSIMPLIS, 1994.*

topography, add a few more centimetres to the tidal range. The annual and semi-annual components of sea level variability are also non-trivial although their forcing is mostly non-astronomic.

THE TIDES AT THE EVRIPOS STRAIT

The most well known tidal feature in Hellas relates to the currents in the Evripos Strait. The reported values for these tidal currents are as high as 4.4 m/sec i.e. in excess of 8 knots, though model estimates are about 7 knots. The width of the strait at its narrowest point is of the order of ten of metres. Thus the tidal signal is choked at the strait and very little energy is transferred between the north and the south Evvoikos Gulf. As a consequence, the sea level of both gulfs oscillates independently of each other and causes significant sea level differences and strong currents across the Evripos Strait (see the model of TSIMPLIS, 1997).

In particular, the tide reaches the south part of the north Evvoikos Gulf later than it reaches the northern part of the south Evvoikos Gulf. Moreover, the tidal amplitude is lower at the southern opening of the south Evvoikos Gulf than at the north opening of the north Evvoikos Gulf, due to the standing wave nature of the semi-diurnal tide within the Aegean. The tides are further enhanced while propagating through the canals of Trikeri and Oreoi in the north Evvoikos Gulf. As a result, the north Evvoikos oscillates everywhere with amplitudes which are virtually the same everywhere in the basin and have for the semi-diurnal tides M_2 and S_2 typical amplitudes and phases of 19.7 cm (92˚) and 13.5 cm (129˚) respectively. In contrast, the southern Evvoikos Gulf has much smaller tides (typically M_2 2.4 cm 76˚, S_2 1.2 cm 80˚). Thus the six-hourly variation of currents is produced mainly by the relatively large semi-diurnal tides of the north Evvoikos Gulf, which introduce six- hourly changes in the sign of sea level differences between the two gulfs. For further details on the circulation pattern at the Evripos Strait see Chapter III.1 (Hydrology and Circulation in Coastal waters).

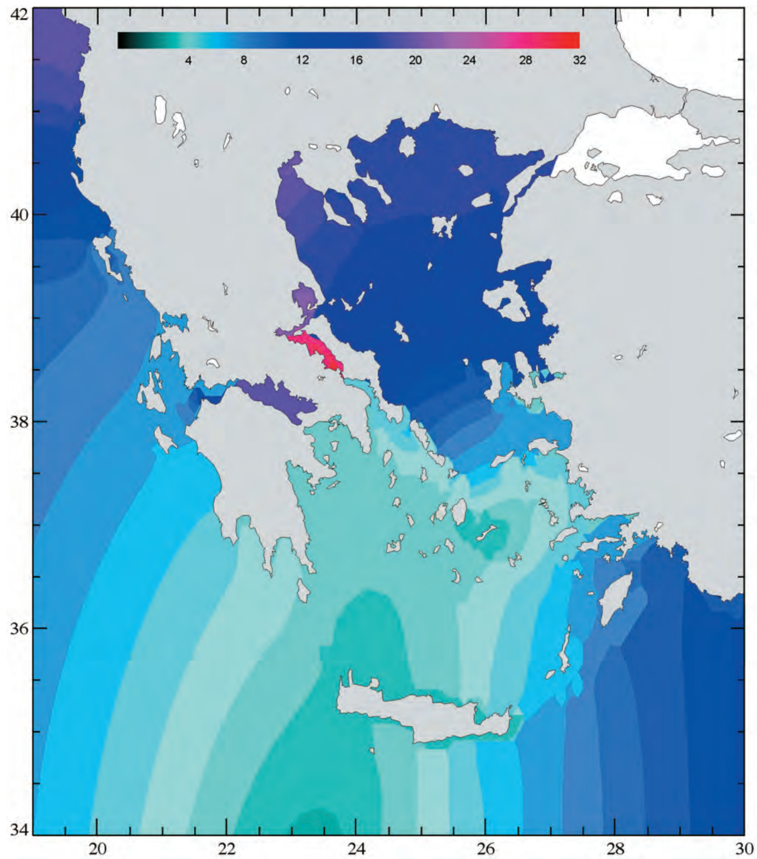


Figure II.14:
The sum of the four major tidal components in the Hellenic Seas from the tidal model of TSIMPLIS et al. (1995).

II.5. THE ATMOSPHERE AS A SOURCE OF NUTRIENTS AND POLLUTANTS TO THE HELLENIC SEAS

In addition to the direct forcing through weather systems and heat exchanges, the atmosphere can have an impact (either positive or negative) on biological processes in the sea via transport of pollutants or essential nutrients such as iron, nitrogen and phosphorus from the continents to the ocean.

It is well known that chemicals both of human and natural origin can reach the open ocean by a number of pathways including rivers, direct dumping and the atmosphere. The first two pathways have been studied for several decades and only recently it became possible to estimate the amounts of chemical substances entering the ocean through the atmosphere. Recent estimates suggest that, on a global basis, the atmospheric route gained importance relative to the other two paths. Indeed at the most up-to-date overview on the atmospheric input of trace species to the world ocean, DUCE *et al.*, 1991 reported that for all the organic species of human origin (like Polychlorinated Biphenyls (PCBs), DDTs, pesticides, etc.) the atmosphere is by far the dominant transport pathway to the global ocean since it accounts for up to 99 % of the amount found in the ocean. For essential nutrients like dissolved forms of N, P and Fe both DUCE *et al.*, 1991 and JICKELLS, 1998, have shown that on a global basis riverine and atmospheric inputs are of similar significance. In addition, JICKELLS, 1998 proposed that in coastal areas and enclosed seas terrestrial inputs (rivers plus atmospheric deposition) play a crucial role in regulating the productivity of sea water. The oligotrophic properties of the Mediterranean Sea and especially its eastern basin have attracted the attention of many investigators who have characterised this area as one of the less productive of the world on the basis of its low nutrient levels and poor productivity. Despite the important role of atmospheric deposition on biological processes in the sea and the fact that the Mediterranean Sea is an enclosed basin surrounded by areas representing important sources of pollutants and nutrients (like N species) or terrigenous elements (Sahara Desert source of nutrients like Fe, P, etc.) very limited information on the atmospheric deposition of nutrients and pollutants into the Hellenic seas exists. This chapter presents a synthesis of existing measurements related to the role of the atmosphere as a source of nutrients and pollutants into the Hellenic seas. It is limited, however, to two compounds: Dissolved Inorganic Nitrogen (DIN) for the class of nutrients and PCBs for the class of pollutants. The main reason is the absence of long-term data for compounds like P, Fe or other important nutrients and pollutants. Note also that apart from the Finokalia station there is no other station in Hellas reporting long term data on the deposition of nutrients and/or pollutants.

METHODOLOGY-SAMPLING SITES

The total deposition of chemicals into the ocean from the atmosphere is the sum of the amounts transferred in gas, liquid and particulate phases. The processes by which materials are transferred from the atmosphere into the ocean in gas and particulate phases are called 'dry' deposition. Liquid deposition is referred as 'wet' deposition and comprises water and its dissolved gases and solutes together with any insoluble particulate material contained therein (DUCE *et al.*, 1991). Thus 'dry' deposition is a continuous process influenced mainly by the wind speed while the 'wet' deposition is more sporadic.

Long-term measurements of both wet and dry deposition of DIN and PCBs have been performed at a remote site on the Island of Kriti (Finokalia). Previous works from our team have shown that for long-lived species like aerosols and gases (like HNO_3, NH_3 reported in this work) the results obtained at the Finokalia station for these species are representative for the whole southeast Mediterranean, which allows a safe extrapolation of our land-base station results. However, given the importance of atmospheric deposition it is clear that data from at least one additional station in the northern Aegean is needed.

The results of the total deposition (wet + dry) are compared to data of Particulate Organic Nitrogen (PON) and PCBs obtained in the Cretan Sea using sediment traps deployed at various depths down to 2 000 m. Sediment traps were deployed to estimate new production (DUGDALE & GOERING, 1967). New production is defined as the phytoplankton growth supported by nutrients supplied from outside the euphotic zone (DUGDALE & GOERING, 1967). Over annual time scales the amount of material that leaves the euphotic zone will equal the nutrient supply from outside the euphotic zone (new production). For the pollutants, which are not influencing at least directly the new production, the sediments traps' data can be used for constructing a mass balance between import (atmosphere) and export (sediment).

There is extensive literature available on the shortcomings regarding the use of sediment traps. Nonetheless, they are extensively used because an alternative approach does not yet exist.

Sampling

Wet deposition: Rain water was collected on an event basis using a wet-only collector installed at Finokalia (25˚60'E, 35˚24'N) a small village on the northern coast of Kriti Island (Figure II.15). Details about Finokalia can be found elsewhere (MIHALOPOULOS *et al.*, 1997).

Dry deposition: Dry deposition was estimated based on the collection of particles on a flat surface covered by glass beads, positioned in a funnel and situated three metres above the ground. The deposition measured using this technique corresponds to the total deposition. However, since from May to September no rain events occur, the measured total deposition during that period corresponds to the dry one. The glass-bead system was exposed to the atmosphere for a week and after that period it was washed with ultra pure water, which was then filtered and processed as the rain water sample. Although this approach could have several limitations, it could provide useful information for total deposition estimation of gases and aerosols. Note also the absence of well established techniques for the direct determination of dry deposition.

Chemical analysis

Analysis of DIN was performed using ion chromatography. For PCBs the analytical method used is described in detail by MANDALAKIS & STEPHANOU (2002).

Sediment traps

Sediment traps have been deployed during two yearly surveys performed in the framework of European funded project MATER (from 4/1997-3/1998 at both sites MST1 and MST2 (Figure II.15) and ADIOS (5/2001-5/2002 southern Peloponnisos, not shown in Figure II.15). Details about the sediment trap preparation, deployment, and laboratory processing of the samples are given at STAVRAKAKIS *et al.*, (2000).

Total deposition of DIN

To facilitate the comparison with the sediment trap data, total deposition of DIN is reported on a 15-day basis (Figure II.16). Wet deposition of DIN presents a clear seasonal trend with higher values in winter compared to summer. The yearly wet

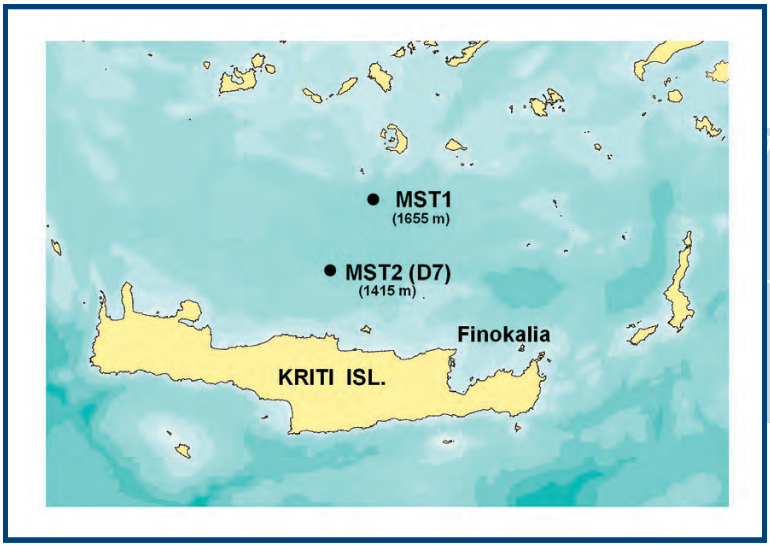


Figure II.15:
Map indicating the location of the sampling sites referenced in the text.

deposition of DIN deduced from long-term measurements at Finokalia since 1997, ranges from 12.8-18.2 mmol/m^2.

Figure II.16 reports the variation of dry deposition of DIN. The dry deposition presents also a distinct seasonal variation with high values during summer. From April to September dry deposition is estimated to be of the order of 26 mmol/m^2, i.e. a factor of 1.3-2 higher than the annual wet deposition. Again long-term measurements of dry deposition confirm the above value (dry deposition ranges from 22-30 mmol/m^2).

Particulate Organic Nitrogen (PON) flux estimation using sediment trap deployments (exported N)

Figure II.14 presents the flux of Particulate Organic Nitrogen (**PON**). Flux of PON ranges from 0.055 to 1.204 mmol/m^2/15days with a distinct seasonal variation, of higher values occurring during the end of winter and the beginning of spring. On a yearly basis the PON flux was estimated to vary between 10.4 – 11.9 mmol/m^2, up to a factor of 1.5 lower compared to wet deposition and up to a factor of 2.5 lower compared to dry deposition. To stress the important role of wet deposition, which, although sporadic, can bring considerable amounts of DIN to the sea surface, in more than 95 % of the rain events the DIN wet deposition equalled the sinking particulate N flux and in 70% of the events this value was 5-times the corresponding PON value. Figure II.16 compares the atmospheric inputs of DIN to the PON fluxes measured using the sediment traps. Dry deposition alone accounts for about a factor of 2 of the collected PON and both dry and wet deposition account for about a factor of 3 to 4 of the PON. Thus airborne DIN alone is more than sufficient to explain new production in the eastern Mediterranean Sea.

Atmospheric DIN deposition and seawater productivity: A still open question.

Based on the data obtained from Finokalia we estimated an annual deposition of DIN (both wet and dry) equivalent to 45.2 mmol/m^2. If we assume that all of this DIN is available to the phytoplankton for new production we can convert the nitrogen flux into carbon uptake using a Redfield C:N ratio of 6.625. Atmospheric nitrogen can, therefore, fix on a yearly basis 30 molC/m^2. A (f) ratio due to external input DIN can be deduced by comparing this value to that derived from measurements of primary production by IGNATIADES (1998) and depicted in Table II.2.

The thus calculated (f) ratio has a mean value of

Table II.2: *Seasonal variation of primary productivity deduced from 'in situ' measurements, primary productivity estimated from atmospheric DIN deposition and (f) ratio.*

Season	PP- *'in situ'* mgCm^{-2}d^{-1}	PP- (N) mgCm^{-2}d^{-1}	(f) ratio
Winter	76.8	4.33	0.06
Spring	50.4	10.47	0.21
Summer	27.6	16.65	0.60
Autumn	26.4	7.79	0.29
Annual average	45.3	9.81	0.29

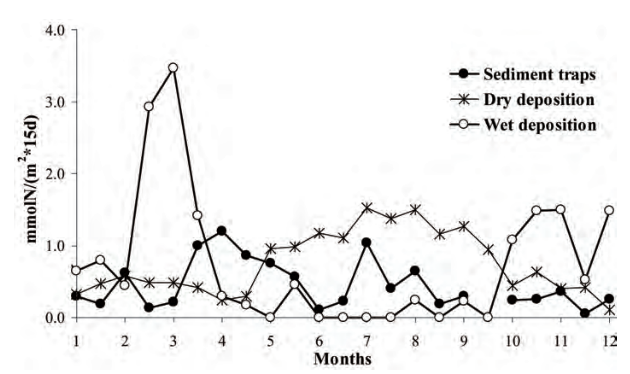


Figure II.16:
Comparison between PON fluxes with both dry and wet deposition at Finokalia.

0.29, i.e. significantly higher than the value assigned to oligotrophic areas (0.05-0.2). Thus from N point of view the eastern Mediterranean is not oligotrophic. This result does not necessarily imply that other processes, such as advection and or nitrogen fixation proposed by several authors as possible sources of N, are of minor importance. It simply shows that the atmosphere alone through DIN deposition can supply the entire required N, in 100% bioavailable form.

Other elements (like P) should be responsible for the oligotrophic status of the eastern Mediterranean. Based on preliminary work by MARKAKI *et al.*, 2003 the atmospheric deposition of DIP could reasonably account for a significant part of the new production (up to 38%) observed during the summer and autumn period, i.e. when water stratification is at its maximum. Given the importance of the atmospheric pathway as a source of nutrient deduced from these results, it is clear that more work is needed to obtain a clear picture on the potential role of atmospheric deposition on the productivity of Mediterranean waters.

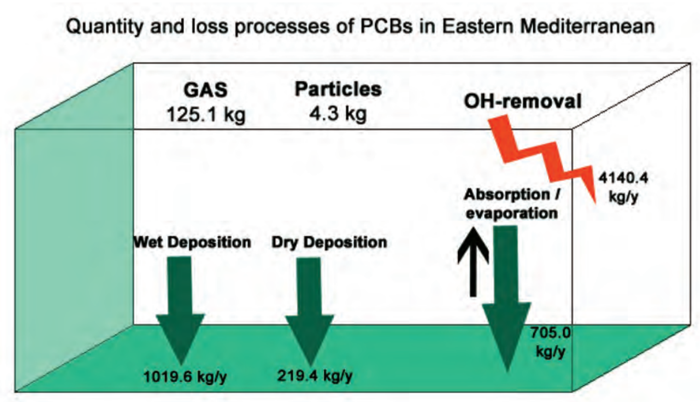
PCBs

Although the production and use of PCBs were banned by the mid-1970s, these chemicals are ubiquitous pollutants in nearly all environmental compartments.

Air, wet and dry deposition samples were collected between April 1999 and August 2002 at the background marine site of Finokalia in the eastern Mediterranean Sea and analysed for PCBs (MANDALAKIS & STEPHANOU, 2002). The average concentrations of total PCB congeners (∑PCBs) in the gas and particulate phase were 68.1±28.8 pg/m^3 and 2.3±1.8 pg/m^3, respectively, comparable to the values reported at other background locations of the northern hemisphere. The lack of seasonal variation for the atmospheric concentration of individual congeners and ∑PCBs indicated that long-range transport is the main factor controlling the atmospheric levels of PCBs in this area. Most of the ‘events’ with elevated concentrations of ∑PCBs concurred with air transport from western and central Europe as indicated by air masses trajectory analysis.

The average concentration of ΣPCB (sum of 54 PCB congeners) in precipitation samples collected from the Finokalia station was 1.9±0.9 ng l^{-1}. Based on these data, it was deduced that the annual wet deposition flux of PCBs should approach 832 ng m^{-2} year^{-1}. The dry deposition flux of ΣPCB ranged between 39 and 394 ng m^{-2} year^{-1} with an average value of 179±125 ng m^{-2} year^{-1}. These values are at the lower edge of the values reported for the western basin.

Calculations based on field data (Figure II.17) have shown that about 1 200 kg y^{-1} are eliminated from the atmosphere through wet and dry deposition. Air-sea exchange is responsible for the elimination of 700 kg y^{-1}, while PCB losses via hydroxyl radicals in the atmosphere may be responsible for the elimination of 4 000 kg y^{-1}. Sediment traps deployed in the same area have shown downward fluxes for total PCBs from 1.1-0.9 ng m^{-2} d^{-1} (depth: 250-2 820 m). These results indicate that only a minor fraction (0.1 %) of the PCBs deposited into the sea water is conveyed to the sediments, the majority is recycled within the euphotic zone by the living organisms.



Source: *MANDALAKIS, PhD Thesis, Univ. of Kriti, 2002.*

Figure II.17:
Quantity and loss processes of PCBs in the eastern Mediterranean.

II.6. PARTICULATE MATTER DYNAMICS AND FLUXES

The study of marine particulate matter composition, dynamics and fluxes has received considerable attention over the past 20 years from a wide range of scientific disciplines, as it has been recognised to play an important role in marine biogeochemical processes. Particulate matter (PM) studies provide information on the origin and fate of materials in the ocean and element budgets (e.g. carbon). Particles can be also used as tracers of circulation and productivity, or for the assessment of pollution and eutrophication. Studies on particulate matter properties were initiated in the 1990s in the HCMR (CHRONIS *et al.*, 2000) and continue till today.

ORIGIN AND CONSTITUENTS OF SETTLING PARTICLES

The PM in the oceans comprises particles deriving from external and internal sources. External particles originate in dust and land run-off, whereas internal particles may originate from a variety of sources, i.e. primary production (phytoplankton), secondary production (zooplankton) and their detritus, sediment resuspension and hydrothermal activity. In the open ocean, most of the PM is of biotic origin. However, in certain areas receiving river discharges, terrigenous (land-derived) PM predominates.

The terms Surface and Bottom Nepheloid Layers (**SNL** and **BNL**, respectively) are often used to describe particulate matter distribution patterns at surface and near-bottom waters, whereas relatively high light transmission and Particulate Matter Concentration (**PMC**) values at mid-depths are named Intermediate Nepheloid Layers (**INL**). The term *flux* is defined as the measure of the rate of transport of settling particles from one reservoir to another and from one physical or chemical state to another. The unit of particle flux is mg m^{-2} d^{-1}. Particle flux can be measured when there is advective (horizontal transport) and/or vertical movement. In the ocean, particles execute the resultant of the aforementioned movements.

Particle flux in the marine environment is a unique phenomenon, which includes a variety of mechanisms, which function in the temporal and spatial scale and numerous interactions between the biotic and abiotic world are involved.

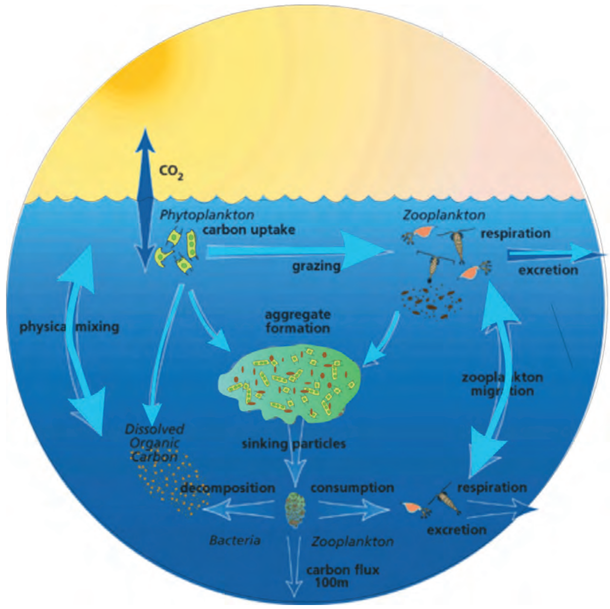
Particle flux is one mechanism that controls the transfer of carbon exported from the atmospheric CO_2 to the deep waters. The complex biogeochemical processes that remove carbon from the ocean's surface by photosynthetic uptake, transport organic matter to the deep sea and remineralise the organic matter are referred to as the biological pump (Figure II.18). The biological pump has a major impact on the distribution of total carbon as well as on nutrients. Components of the biological pump are responsible for transforming dissolved inorganic carbon into organic biomass and pumping it in particulate or dissolved form into the deep ocean. Numerous and complex processes cooperate to export particles from the upper ocean to deep waters which involve phytoplankton communities, marine animals, microcosm and land-derived material. The final products can be divided into four main particle groups:

Organic matter

Phytoplanktonic organisms as well as zooplankton produce organic matter. The major part of export production 'pumped' into the deeper water column is remineralised during sinking. About 1% of the particles leaving the surface ocean reaches the sea bed and are consumed, respired, or buried in the sediments. Rivers can also input organic matter into the ocean but most of this input remains in the continental margin environment.

$CaCO_3$

There are three main sources of $CaCO_3$ particles in the marine ecosystem. The first one is the group of phytoplankton, which produces calcareous exoskeleton, the majority of which are coccospheres and coccoliths (Figure II.19). The second is zooplanktonic shells of planktonic foraminifera and the third is aragonite shells of pteropods.



Source: *http://usjgofs.whoi.edu*

Figure II.18:
Schematic description of the biological pump.

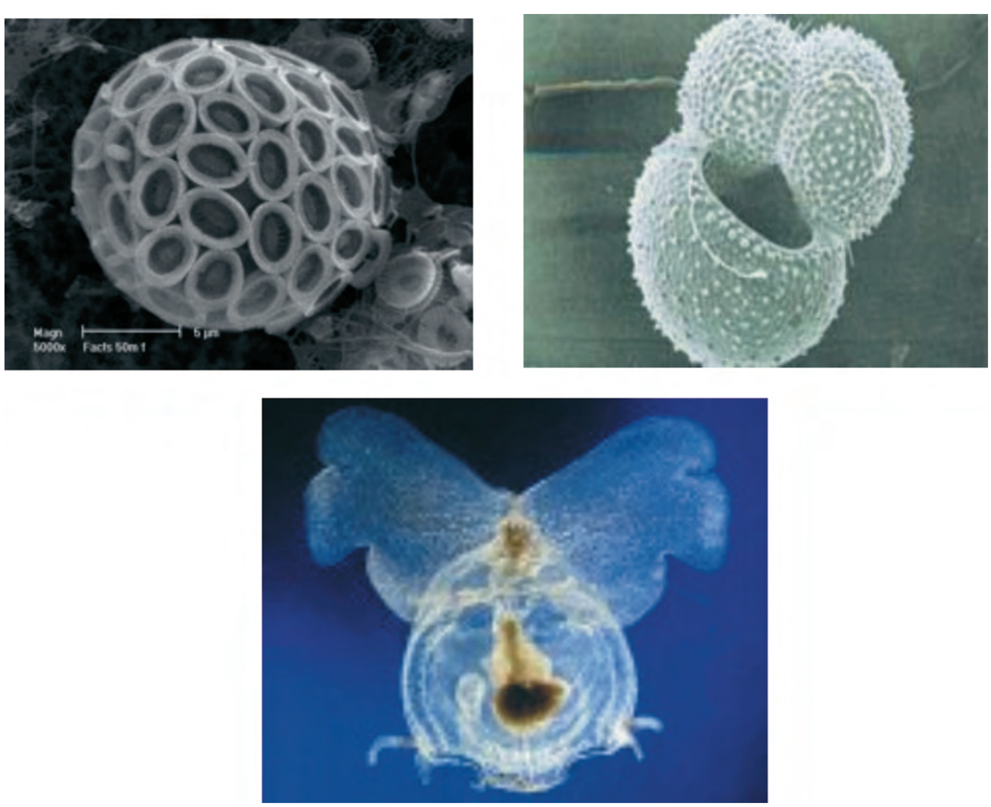


Figure II.19:
Coccolithophore Emiliania huxley (left), Foraminifera (right) and Pteropoda (center).

Biogenic Silica - Opal (SiO_2)

Opal is mainly composed of diatom shells (Figure II.18). Radiolaria and secondary silicoflagellates are other important sources of biogenic SiO_2 (Figure II.20).

Lithogenic material

Lithogenic particles are transported from the continents to the ocean's surface following two main pathways. Winds can carry large quantities of dust and supply the ocean with terrigenous material. For the Mediterranean Sea, the main sources of dust are the Asian and African deserts (Figure II.21). Rivers discharge a huge amount of terrigenous particles (Figure II.19) but only a small percentage of fine particles reaches the bottom of the open sea; the main part of the riverine load is deposited in the adjacent areas of the continental margins and slopes.

METHODS OF MEASURING PM

Widely used particulate matter measurements include quasi-synoptic (particulate matter concentration, transmissometry) and time-series methods (sediment traps), which have been applied during our experiments and are briefly described as follows.

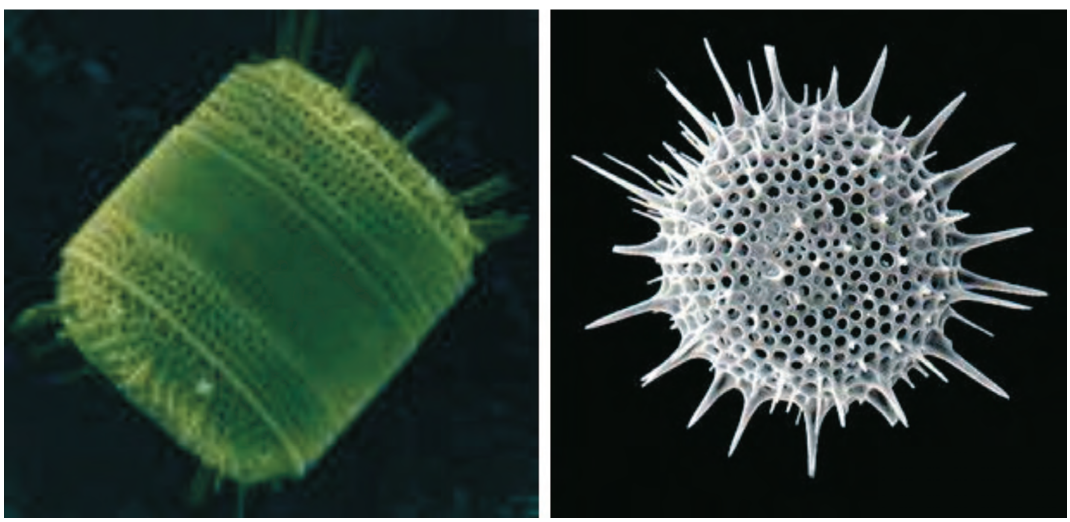


Figure II.20: *Diatom (left) and radiolarian (right).*

Figure II.21: *Saharan dust over the Mediterranean Sea (left); satellite image of the Axios River plume showing impressive sediment discharge (right).*

Source: *KARAGEORGIS et al., 2000.*

Particulate matter concentration (PMC)

Sea water is routinely collected at various depths in Go-Flo 10-l bottles mounted on a rosette (Figure II.22). Dry-weight particulate matter concentration (PMC) is determined by onboard sea water filtration through preweighed membrane filters (pore size 0.45 μm). In cases where a high quantity of PM is required for analyses, *in-situ* underwater high volume filtration pumps are used.

Transmissometry (LT)

Particles in the water column cause attenuation of light due to scattering and absorption processes. The most commonly used tools measuring light attenuation are the transmissometers (Figure II.22). Transmissometers are deployed together with other instruments (usually named as CTD, which employs sensors measuring depth, conductivity, temperature, oxygen, fluorescence, etc.; Figure II.22) from the sea surface down to a few metres above the bottom and provide continuous readings of light transmission (LT) vs. depth. In general, light attenuation is linearly correlated to PMC, if certain conditions are satisfied (BISHOP, 1986). A significant correlation (r> 0.85) between PMC and LT allowed for the conversion of transmissometer readings to PMCs, thus produced PM spatial distribution maps are expressed in mg l^{-1} throughout the document.

Data presented here were obtained in the framework of the EU-funded Projects CINCS (CHRONIS *et al.*, 2000), Metro-Med (KARAGEORGIS & ANAGNOSTOU, 2003) and MATER (LYKOUSIS *et al.*, 2002) and the concurrent Hellenic Projects INTERREG-North Aegean and INTERREG-Ionian Sea (SIOULAS *et al.*, 2001). Data were archived in Ocean Data View software (SCHLITZER, 2003). Similar, but scattered (both in time and space) data are available from other Hellenic regions, however, the north Aegean Sea dataset is most suitable for providing a general description of PM dynamics in the Hellenic Seas (Figure II.23).

Sediment traps

Mooring lines were instrumented with two sediment traps (PPS3/3 Technicap with 0.125 cm^2 collecting area and 12 receiving cups; Figure II.24) and deployed for two six-month periods. All bottom traps were set 35 m above bottom.

Upon recovery of the trap, samples are stored at 2˚C in a dark room until treatment. The most time-consuming and tedious work is the preliminary treatment of the samples, swimmers removal (zooplankton or nekton that enter sediment traps actively and are not part of the true flux), sub-sampling and preparation of filters for various

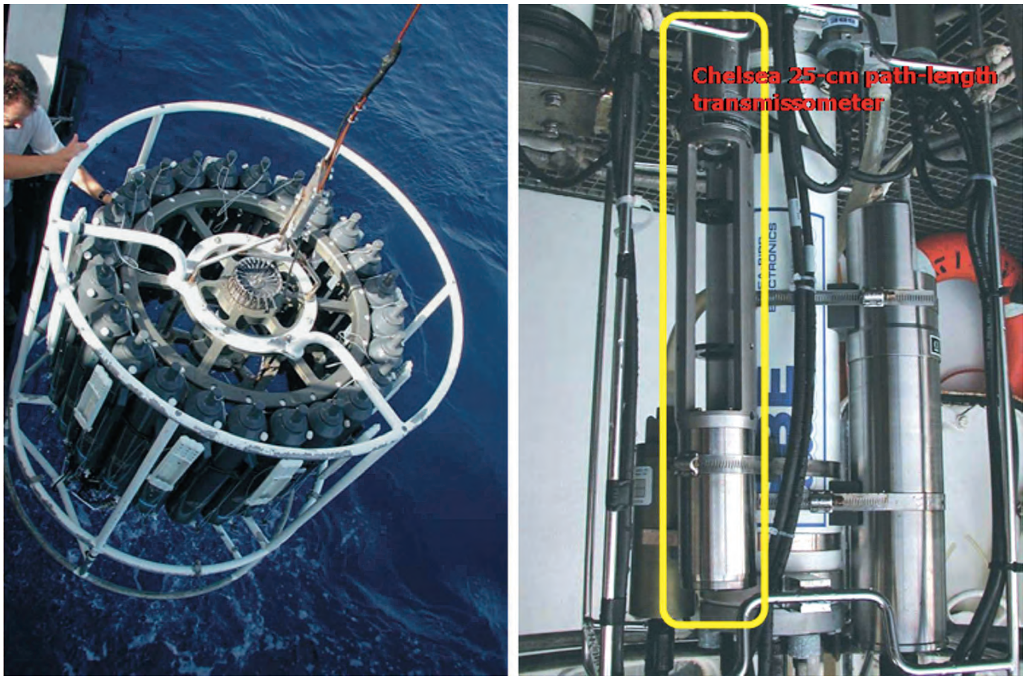


Figure II.22: *Deployment of the rosette/CTD system from the R/V Aegeao (left); the Chelsea transmissometer mounted under the rosette together with other sensors (right).*

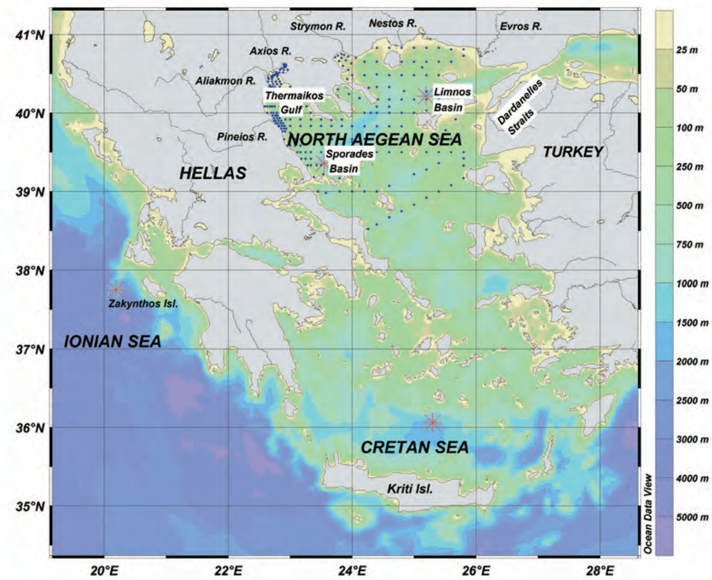


Figure II.23:
Study area location map. Light transmission and bottle data stations are shown by blue dots and sediment trap locations by red stars.

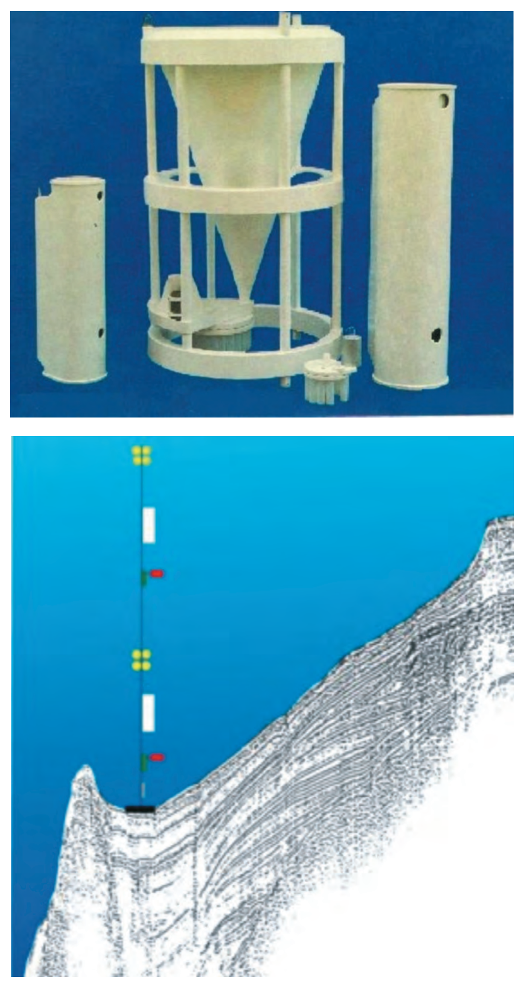


Figure II.24:
Types of sediment traps (above). Schematic representation of a mooring line instrumented with two sediment traps (white), two current meters (red) to measure the current speed and direction, buoys (yellow) to keep the line in an upright position and carry the line back on the sea surface, acoustic releaser (grey) and anchor weights (black) (left).

analyses. Swimmers are removed by sieving the sample through 1 mm nylon mesh and then by hand under a microscope. The preparation of the sediment traps, the laboratory processing of the samples, including preliminary treatment, swimmers removal and sub-sampling is according to HEUSSNER *et al.* (1990).

Total mass fluxes and fluxes of major constituents of: (i) Organic matter: organic C; (ii) $CaCO_3$: Inorganic C; (iii) Biogenic SiO_2 (opal); and (iv) Lithogenic fraction, are determined for all samples. For simplicity, in the present contribution data only for the total mass flux (TMF), which is the sum of the aforementioned constituents, will be presented.

Data discussed here have been collected during the Projects Metro-Med, MATER and INTERREG-Ionian, which include many moorings, whereas the most representative have been selected for the present compilation.

PARTICLE DYNAMICS IN THE NORTH AEGEAN SEA

During spring (high river discharge period), PM distribution patterns are characterised by elevated values in the vicinity of the rivers discharging into the north Aegean Sea (Figure II.25). The river plumes mostly affect the SNL: the Axios, Aliakmon, Pineios, Strymon, Nestos and Evros rivers' influence is easily distinguished by elevated PMC values in front of their mouths (PMC range 1-6 mg l^{-1}; note that SNL data near the Evros River are missing, but the Evros River's influence can be recognised at the 20 m depth layer). The central and southern part of the area under investigation is characterised by more transparent waters (PMC 0.2-0.6 mg l^{-1}). Similar patterns are observed nearshore, at the 20 m depth layer, but PMC values are quite lower, in the range 0.4-1.6 mg l^{-1} (Figure II.25); as a result, river plumes are less pronounced. During autumn (low river discharge period), PMC values are substantially lower at the surface waters, compared to springtime (Figure II.26). The signal of the rivers is weak and can be recognised only near the river mouths (Thermaikos Gulf only).

The 50 m depth layer is characterised by low PMC values during spring and autumn for the entire north Aegean Sea. The deeper layers (100 and 200 m) are dominated by the lowest PMC values, in the range 0.1-0.4 mg l^{-1}. The latter distribution patterns are almost identical; depicting that main particle transport takes place only at the surface layers. In addition, the absence of enhanced PMCs at the shelf break (around 200 m depth) shows that particle transport from the shelf to the deep sea is very limited throughout the year.

The BNL distribution patterns are particularly interesting, because they are related to PM deposition and resuspension processes. During both measurement periods, the BNL is pronounced especially near the river mouths but also all over the entire continental shelf. However, during spring, the BNL is enhanced notably, meaning that freshly supplied riverine particulate matter is more subject to resuspension. The BNL formation is generally attributed to resuspension due to wave and near-bed currents action. Near-bed currents may lift fine-grained material from the sea bed even at very low velocities, less than 10 cm s^{-1} (GARDNER, 1989).

Vertical PM distribution patterns are generally characterised by turbid SNL and BNL, separated by relatively particle-free intermediate waters (not shown here). Weak INLs were only observed during springtime (and winter), detaching at the shelf-break and subsequently dispersing horizontally into the open sea (KARAGEORGIS & ANAGNOSTOU, 2003).

PM distribution in the north Aegean Sea is largely controlled by river inputs and water-mass dynamics. High PMC values are observed in front of the river mouths and affect the upper 0-20 m of the water column. Deeper waters are less influenced and appear to have quite uniform and constant PMCs. In the Thermaikos Gulf, the particulates are transported to the south, under the forcing of water-mass dynamics (cyclonic circulation prevails throughout the year), mostly driven in the upper layers by the dominant wind. The neighbouring Dardanelles Straits, where Black Sea waters are mixed with Aegean waters, do not seem to supply a distinguishable amount of PM, as PMCs were found to be generally low, during both spring and autumn seasons.

PM deposition is taking place either exactly in front of the river mouths, or at a short distance farther offshore, but always within the limits of the shelf. Recently deposited particles are easily resuspended by near-bed currents, generating a turbid benthic nepheloid layer over the shelf. Very little PM is entering the slope and the deep-sea areas.

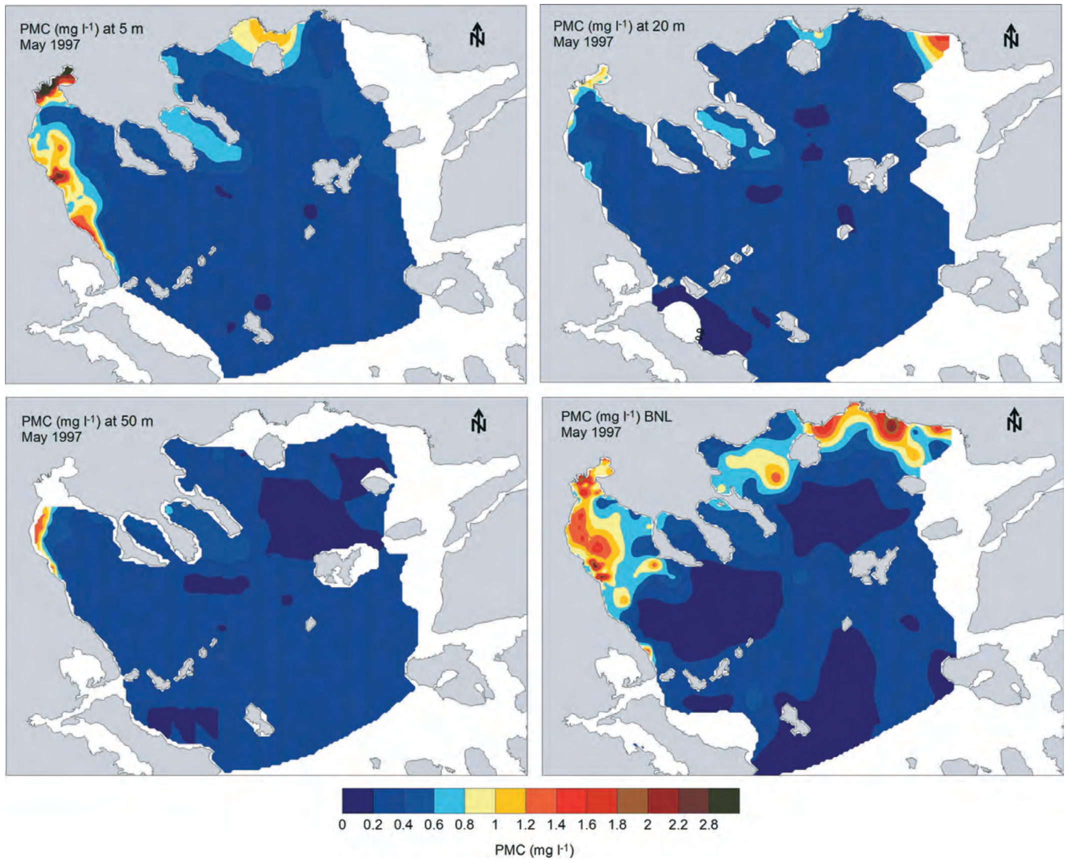


Figure II.25: *Particulate matter concentration (PMC) distribution patterns (mg l $^{-1}$) over depth during May 1997 (spring).*

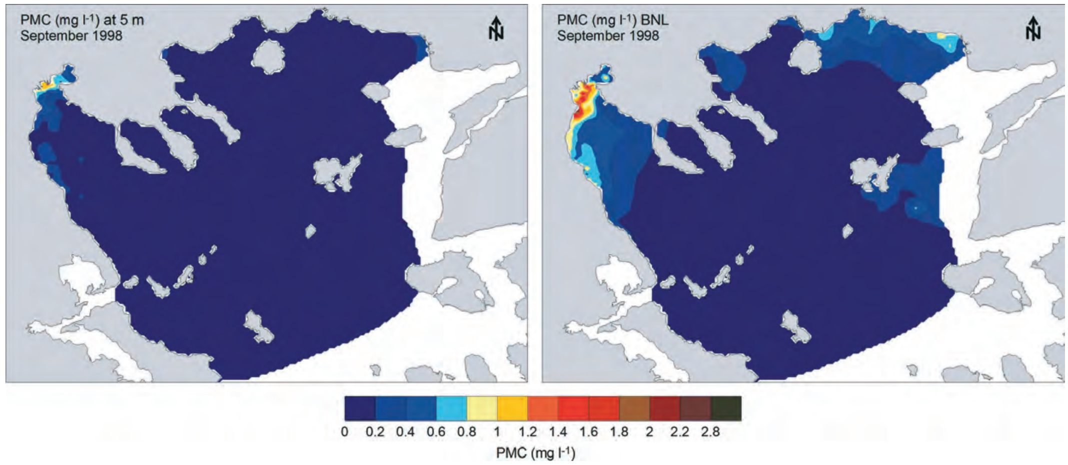


Figure II.26: *Particulate matter concentration (PMC) distribution patterns (mg l $^{-1}$) over depth during September 1998 (autumn).*

PARTICULATE MATTER FLUXES

Temporal and spatial variability of total mass flux

i. Limnos Basin

The material collected at both levels (500 and 1 213 m; Figure II.27) represented a seasonal signal with low mass flux from May to September and high from October to April. Three major peaks were observed at the bottom trap; in April with 2 317 mg m^{-2} d^{-1}, in December with 3 467 mg m^{-2} d^{-1}, and in March with 3 741 mg m^{-2} d^{-1}. At the 500 m depth trap the seasonal signal was strong. Three peaks that were observed in November (1 764 mg m^{-2} d^{-1}), December (1 717 mg m^{-2} d^{-1}) and March (1 361 mg m^{-2} d^{-1}) are in agreement with the pattern of the near-bottom flux.

ii. Sporades Basin

Temporal variations of *TMF* at both depths (500 and 1 135 m; Figure II.27) showed almost the same pattern from April to December 1998. Moreover, *TMF* values at both depths were quite similar from June to September. The identical mass flux sequences could indicate that the mechanisms, which control the particle transfer at that period of the year, were quite similar at both depths. From December to the end of the experiment *TMF* was higher at 500 m and temporal variations as well values at the two depths did not match.

iii. Cretan Sea

Time-series of *TMF* at both depths (500 and 1 655 m; Figure II.27) showed a strong seasonal signal, but at that site fluxes were higher in summer and lower in winter. At 500 m depth five peaks were recorded. Fluxes showed a weak tendency to decrease during the experiment. On the other hand, the decreasing trend at near-bottom trap was strong, since values decreased gradually from 340 to 26.6 mg m^{-2} d^{-1} and then down to 10.9 mg m^{-2} d^{-1} with an indication of increase at the end. At that depth, two major peaks were observed (340 and 179 mg m^{-2} d^{-1}). Despite the long distance between the two traps (~1 100 m), the quite similar pattern of mass flux during most of the winter is noticeable at both levels.

iv. Ionian Sea

Due to a malfunction of the electronic device of the bottom trap no samples were collected from

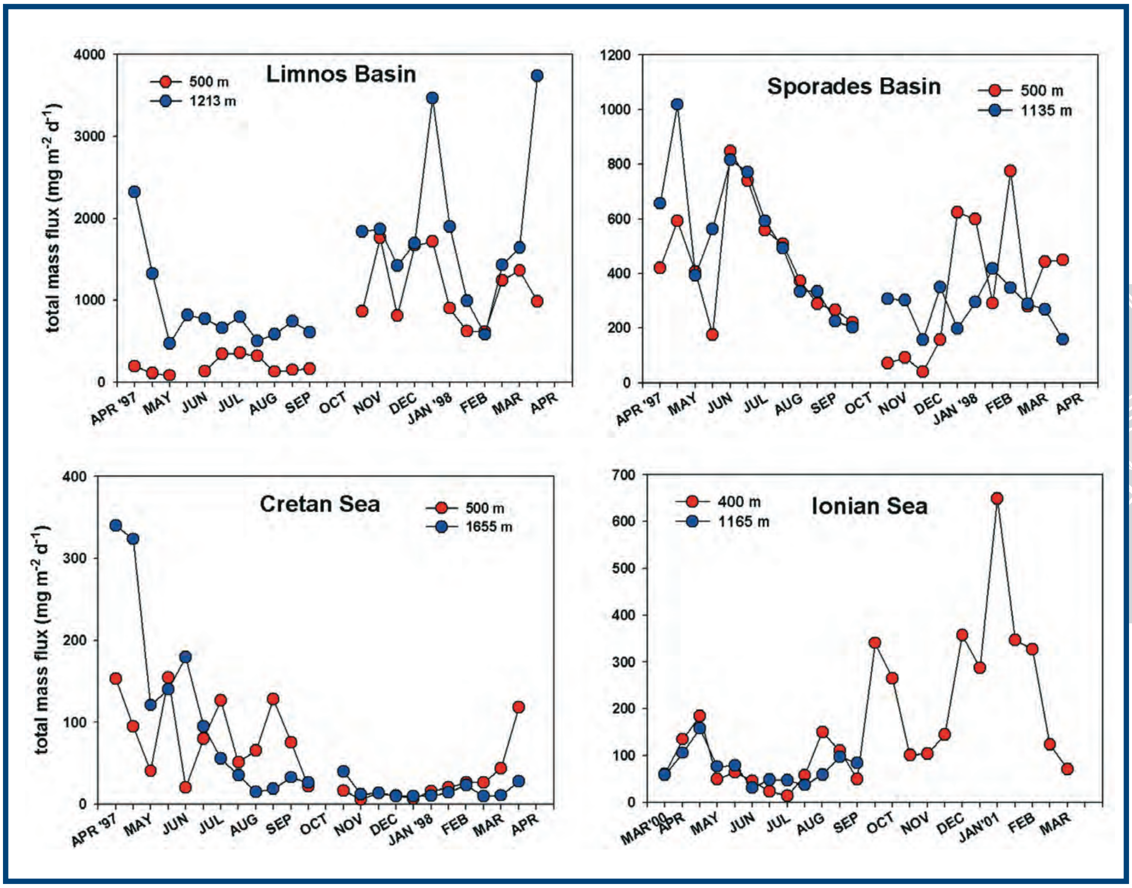


Figure II.27: *Time-series plots of total mass flux (mg m^{-2} d^{-1}; note the different y-axis scale).*

September 2000 to March 2001. During the time when the two traps operated, *TMF* changed in an almost identical manner (Figure II.27). The time-series plot showed a strong seasonal signal with low *TMF* in spring and summer and high in autumn and winter at 400 m and two maxima were recorded in September (341 mg m^{-2} d^{-1}) and January (649 mg m^{-2} d^{-1}).

Particulate matter concentrations and fluxes in the Hellenic Seas

In this section a comparison of PMCs and PM distribution patterns as well as total mass fluxes between the north Aegean Sea, the Cretan Sea and the Ionian Sea is made.

Maximum PMC values recorded during spring in the three regions reveal that the north Aegean Sea exhibits by far the highest values (~6 mg l^{-1}), the Ionian Sea shows three-fold lower values and the Cretan Sea shows very low values (Figure II.28). This pattern is not consistent during autumn, where all the three regions exhibit similar maxima at ~1 mg l^{-1}. Minimum PMC values exhibit very low values during autumn, with the exception of the Cretan Sea. Comparing average values we may distinguish the north Aegean Sea as the region showing highest values during spring (~0.6 mg l^{-1}). Average PMC values in the Cretan Sea are remarkably high during both spring and autumn; given that this region receives minimal terrigenous supply and is also extremely oligotrophic, those relatively high PMC values could not be explained.

It appears that riverine supply controls the particulate matter concentration levels in the Hellenic Seas. The north Aegean Sea receives a substantially higher freshwater and suspended sediment supply from several major rivers, than the Ionian Sea (Kalamas, Acherontas, and Acheloos Rivers) and the Cretan Sea (only ephemeral streams). However, during the period of low river supply maximum PMCs are fairly similar.

As far as it concerns the PM spatial distribution patterns, we may identify the following: (i) higher PMCs are observed near the coast and values decrease rapidly offshore. This pattern is more pronounced in areas where the continental shelf is narrow (Ionian Sea and Cretan Sea); (ii) distinct INLs are formed by a detachment of the BNL at the slope area, which may extend several kilometres offshore in all regions; and (iii) sediment resuspension is

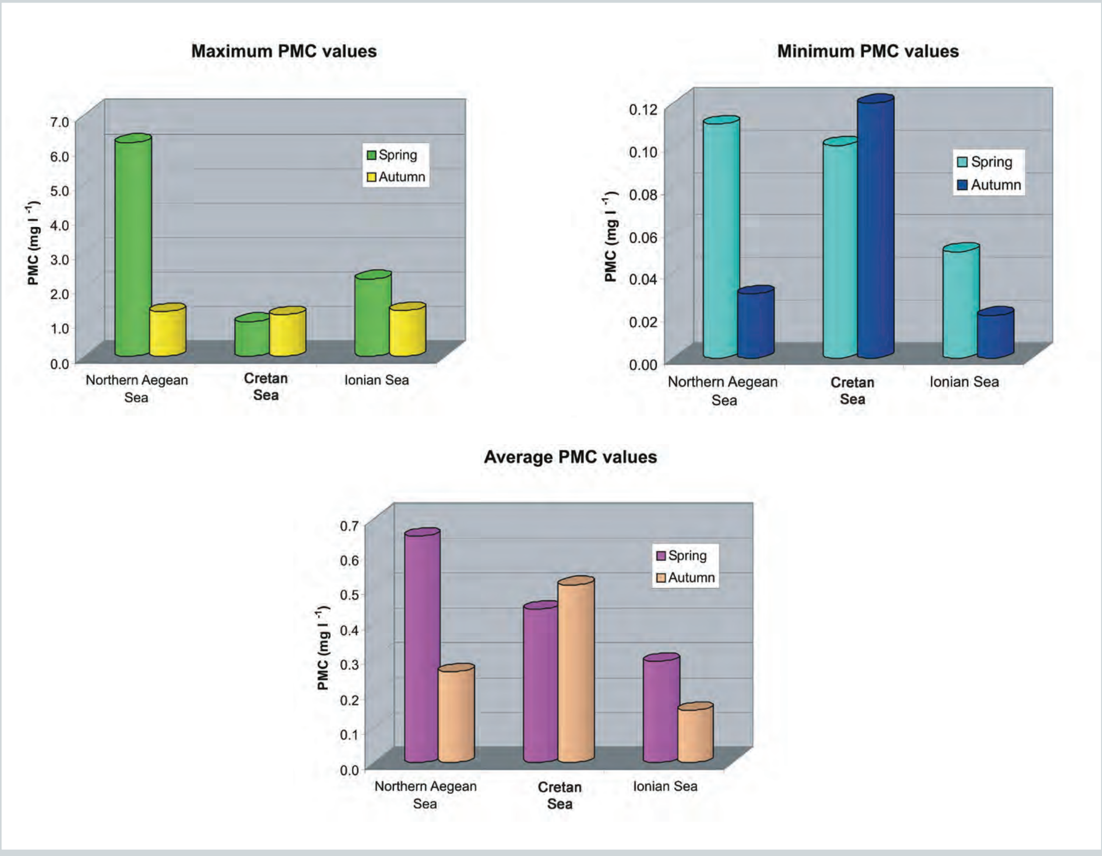


Figure II.28: *Comparison of maximum, minimum and average PMC values during spring and autumn, in the north Aegean Sea, the Cretan Sea and the Ionian Sea (note the different y-axis scale).*

favoured in the north Aegean Sea, particularly during spring, as fresh unconsolidated material supplied by the rivers is abundant and water depths are appreciably shallower than the other two areas.

Concerning the fluxes, the strong total mass flux contrast registered between the north (Limnos and Sporades Basins) and the south Aegean (Cretan Sea) confirms the southward oligotrothy in this part of the Mediterranean, since *TMF* decreased dramatically from the north to the south at both depths (Figure II.29). In the Limnos Basin, *TMF* is almost always higher at the bottom compared to the 500 m depth throughout the experiment. The increase of *TMF* with depth (Figure II.30) indicates that lateral transport is the main factor which governs the particle transport in the area and that is typical for marginal environments.

The feature of higher winter and lower summer *TMF* of the north Aegean is reversed in the south Aegean, where higher values are observed in spring/summer and lower in autumn/winter. This could be explained by the absence of any important river discharges and the effects of atmospheric input (Saharan dust), which is common over the area of the Cretan Sea in April – May (Figure II.29).

In the Ionian Sea, high total mass flux recorded during winter indicates the influence of rivers' discharge into the area. Moreover, the relatively low mass flux is due to lower river discharges when compared to the higher discharges of the north Aegean Sea.

Total mass fluxes in the Hellenic Seas are, therefore, controlled by: (i) river discharges; (ii) eolian inputs; and (iii) biological production. Highest TMF values are generally observed in the north Aegean Sea, whilst lowest values are recorded in the Cretan Sea.

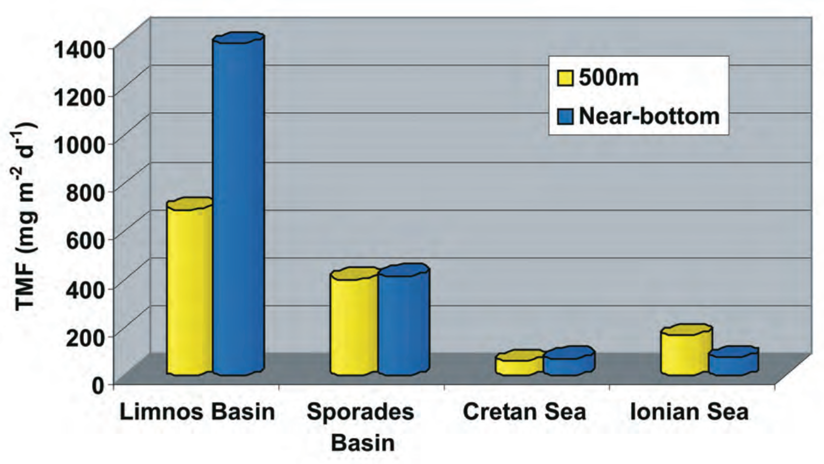
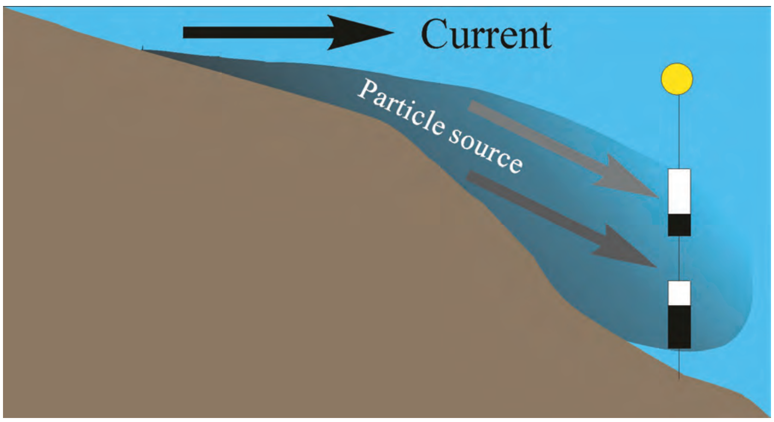


Figure II.29:
Mean annual TMF at 500 m and near-bottom sediment traps. Near-bottom trap in the Ionian Sea represents a sampling period of six months only.



Source: *Modified from HEUSSNER et al., 1990.*

Figure II.30:
Schematic representation of total mass flux increase with depth in a slope environment. Particle-rich waters (dark grey arrow) feed the deepest trap, while relatively particle-free waters (light grey arrow) feed the shallower trap.

II. GAPS IN KNOWLEDGE - FUTURE PERSPECTIVES

Our present understanding of the air-sea-land exchanges in the eastern Mediterranean is based on global data sets or atmospheric models. However, these sources often do not have the spatial resolution required in order to reproduce the multiple scale process involved in the exchanges.

Measurements of air-sea-land interaction, including sea-air exchange and atmospheric deposition are required in order to improve our understanding of the physics of these interactions. Such data are extremely sparse if not absent in the region. Consequently, most evaluations and calibration techniques are based on coastal or inland records, as marine data are non-existent. Integrated direct marine measurements of the complete air-sea-land exchanges are not feasible with the existing infrastructure, although the crucial role of the air-sea-land exchanges in the functioning of the eastern Mediterranean marine system makes the recording of the entire surface flux components imperative. Moreover, such records may serve for the comparison and improvement of the results of oceanic numerical models applied in the region.

Another issue that must be prioritised for research is the role of the oceanic advection in relation to the air-sea exchanges. As mentioned before, in the long term, heat and freshwater transport through the ocean must balance the air-sea exchanges. Because the Aegean Sea communicates with the Mediterranean through the straits east and west of Kriti and with the Black Sea through the Dardanelles, continuous monitoring of currents and hydrographic properties at these locations, will provide a robust constraint to the surface heat and freshwater fluxes of the Aegean Sea.

Light transmission measurements as well as the accompanying PMC measurements coupled with the 'Poseidon' observation network can be used to continuously monitor particulate matter dynamics and fluxes. Such data could then be linked to global change studies and could be used as high-quality input data to numerical models.

Spatial distributions of the mean wave height for the Aegean Sea are based on forecasts from the wave model WAM-cycle 4 forced by the POSEIDON weather forecasting system, during the four-year period 1999-2003. Further comparisons with measurements in the open sea (away from shadow effects due to the presence of islands), as well as use of different initial and boundary wind fields (e.g. from ECMWF), are required in order to evaluate the forecasting skill of WAM in the area of the Aegean Sea.

Linking the derived wave field with its impacts on coastal geomorphology and erosion is a challenging and important subject that needs further research.

The tidal currents are known to be small but are largely unknown. The resolution of the existing tidal models is too coarse to resolve them accurately as the currents are affected by the bottom topography. In addition, most of the models are two dimensional thus they cannot reveal the distribution with depth of the tidal signal. Several deployments of current meters have taken place for a few decades but there does not appear to be a national database in which the data can be gathered, quality controlled, analysed and compared with the model estimates. The description of the tidal signal can be improved by a higher resolution tidal model but, taking into account the small size of the tidal signal, it is unlikely to be of much practical use.

However, the derivation of accurate tidal currents would certainly be welcome to geomorphologists and coastal managers at least in particular areas.

The question whether a sea level rise under global warming scenarios could affect the general character or the importance of the tides in the Mediterranean Basin has not been answered conclusively. However, on the basis of similar studies conducted in more dynamic environments, we can estimate that the mean change will be about 1-2 cm for the Aegean and the Ionian seas and thus it is not expected to be significant.

Better data and longer time-series will hopefully improve our understanding of the driving mechanisms of the air-sea-land fluxes, crucial for the examination of oceanic processes such as the circulation and water mass formation taking place in the eastern Mediterranean.

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CHAPTER III
HYDROLOGY AND CIRCULATION

III.1. COASTAL AREAS: CIRCULATION AND HYDROLOGICAL FEATURES

The Hellenic coastal marine areas are in general characterised by a relatively narrow shelf, i.e., the 100 m isobath is within a 20-30 km distance from the nearby coast, whereas only a few river deltas exist, most of which are in the north Aegean. The freshwater discharge of the Hellenic rivers is minimal so that in each case the riverine water influence on the coastal hydrology is localised in the wider delta vicinity.

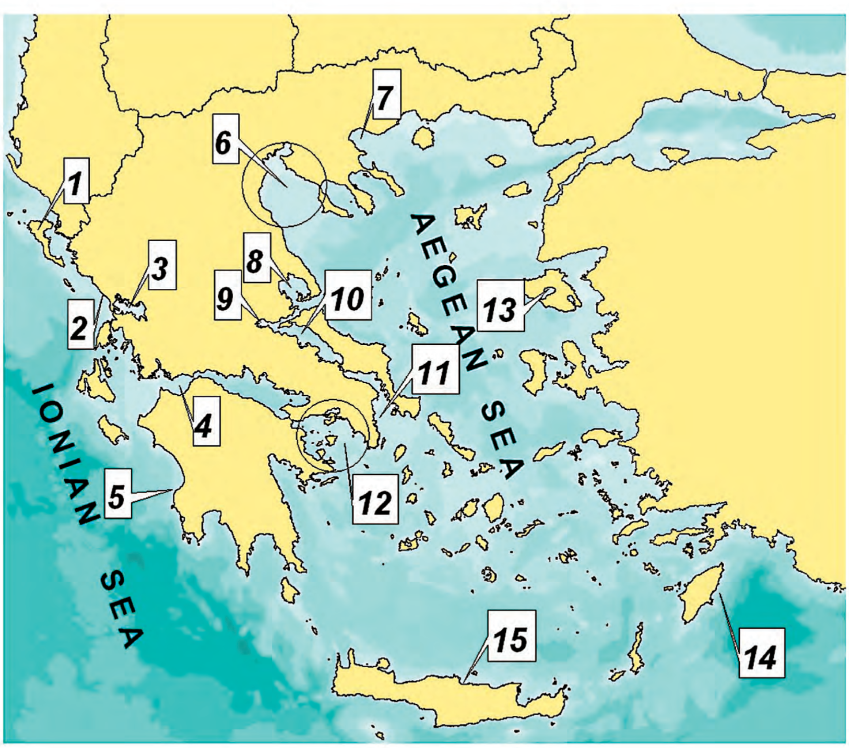
In the last 30 years, numerous marine environmental projects have been conducted in several coastal areas around the Hellenic territory. Despite this long history in coastal work, our overall knowledge of coastal physical processes occurring in Hellas could generally be considered as incomplete rather than detailed. It should be pointed out that the technological advances in measuring techniques, which can ease any research task, have been available only in the last 10-15 years. Today (2004) there are coastal areas, mostly in the vicinity of large cities such as Athens and Thessaloniki, for which our knowledge has really advanced, but there are other coastal areas, which have never been investigated.

We present below an overview of our basic knowledge on coastal hydrological features and circulation by referring to characteristic examples from several coastal areas, which are shown in Figure III.1.

HYDROLOGICAL CHARACTERISTICS

As a result of the small shelf width, the relatively narrow coastal areas undergo:

1) a strong seasonal cycle in the sea water physical characteristics of temperature and salinity that is driven by the atmospheric interaction



1. Kerkyra
2. Ipeiros coasts
3. Amvrakikos Gulf
4. Patraikos Gulf
5. W. Peloponnisos coast
6. Thermaikos Gulf
7. Strymonikos Gulf
8. Pagasitikos Gulf
9. Maliakos Gulf
10. N. Evvoikos Gulf
11. Petalioi Gulf
12. Saronikos Gulf
13. Kalloni Gulf
14. Rodos isl.
15. Kriti (Irakleio)

Figure III.1: *Coastal areas for which hydrological features or circulation structures are presented.*

(heating/cooling, evaporation/precipitation) and

2) a strong influence by hydrological features of the open sea which can massively intrude over the narrow shelf into the coastal areas.

In areas where there is fresh-water input from local rivers, this riverine water is a third factor that carries its own seasonal signal and contributes to the determination of the local hydrologic characteristics.

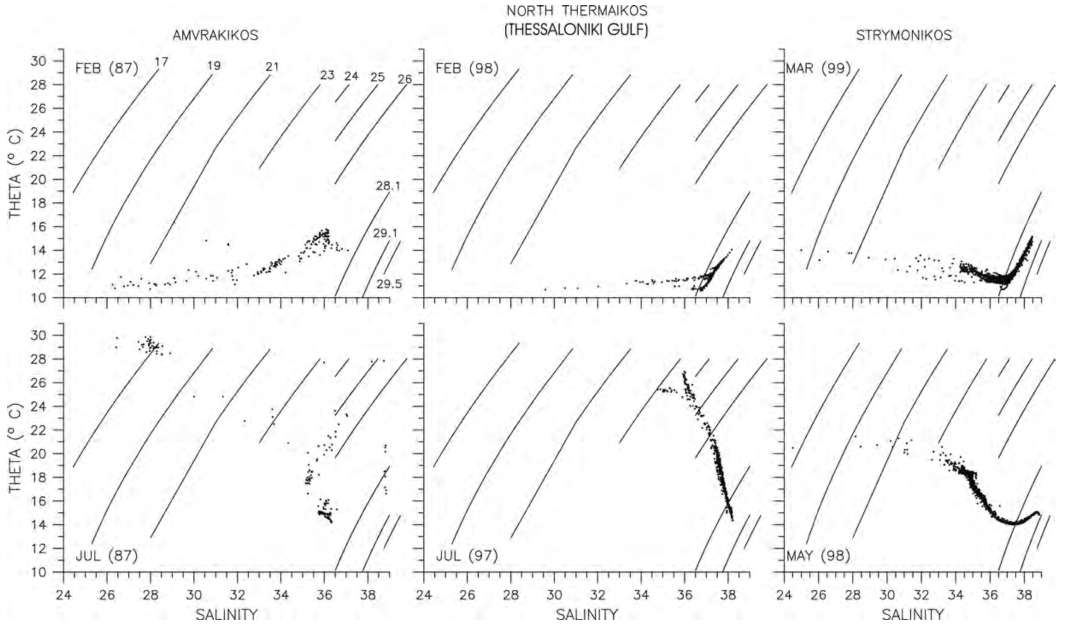
a) T/S distributions

Figures III.2 and III.3 show typical examples of temperature/salinity (t/s) values for the cold and warm seasons in areas such as the northern Thermaikos, Strymonikos and Amvrakikos gulfs, that are influenced by local riverine fresh-water input (Figure III.2) and in areas, such as the Saronikos and Evvoikos gulfs, and the coastal region between Kerkyra and the Hellenic mainland, where the local fresh-water input is practically zero throughout the year (Figure III.3). Salinities as low as 24.0-26.0 can be encountered in the coastal areas where there is a significant fresh-water input into the sea. In the northern Thermaikos Gulf the low salinity signal practically disappears in summer because of human intervention on the already reduced riverine freshwater that flows towards the sea. Coastal areas that are not influenced directly by local fresh-water input have, in general, salinities higher that 38.0 (Figure III.3).

In all coastal areas a strong annual cycle in water temperature exists with high summer temperatures in the surface layer reaching 26.0˚ C or even 28.0-30.0˚ C in more enclosed areas such as the Amvrakikos, Thermaikos and Saronikos gulfs, while the lowest winter temperatures can be as low as 11.0-12.0˚ C. As a result, a strong seasonal thermocline exists during the summer in the layer between ~30-60 m. Table III.1 summarises the observed ranges in the values of temperature and salinity of the above coastal regions during winter and summer.

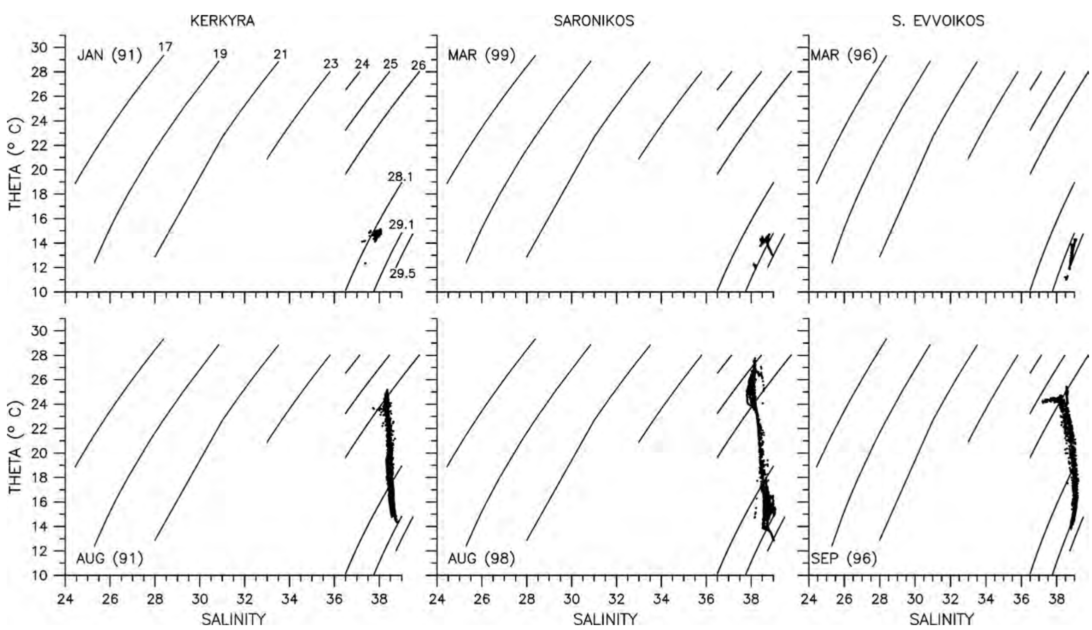
b) Horizontal distributions

In isolated coastal areas such as the Amvrakikos Gulf and the Gulf of Kalloni, with mean depths of ~35 m and ~10 m respectively, extreme values in hydrologic properties can be observed due to the minimal mixing with water quantities of the open sea. The effects of the atmospheric driving are even more striking in cases where the semi-enclosed water body is rather shallow as in the Gulf of Kalloni. Figure III.4 shows surface salinity distributions in the Amvrakikos Gulf in winter (February 1987) and summer (July 1987). In both seasons the gulf is filled with low-salinity water of local origins located in the northern coast of the gulf as is clearly observed during winter.



Source: *BALOPOULOS & PAPAGEORGIOU, 1989; KONTOYIANNIS et al., 2003; PAVLIDOU et al., 2002.*

Figure III.2: *Temperature / sali(T/S) diagrams during homogenisation (upper panels) and stratification (lower panels) periods in representative coastal areas that are influenced by fresh-water input.*



Source: *BALOPOULOS & ZODIATIS, 1992; KONTOYIANNIS & PAPADOPOULOS, 1999; KONTOYIANNIS & PAPADOPOULOS, 1996.*

Figure III.3: *(T/S) diagrams during homogenisation (upper panels) and stratification (lower panels) periods in representative coastal areas that are not influenced by fresh-water input.*

Table III.1: *Typical surface-to-bottom ranges of temperature and salinity in several coastal areas around Hellas during winter (February, March) and summer (August, September), and representative surface/bottom standard deviation values of them (based on CTD data from the Medar Group 2002).*

	WINTER		SUMMER	
	Temperature ° C (Surface-Bottom)	Salinity (Surface-Bottom)	Temperature ° C (Surface-Bottom)	Salinity (Surface-Bottom)
Kerkyra	11-15	37-38	25-14	38-39
Ipeiros coasts	12-15 (at 50 m)	37-38 (at 50 m)	23-16 (at 50 m)	37.5-38.8 (at 50 m)
Amvrakikos G.	10-15	26-38	30-14	26-38
Patraikos G.	12.5-12.5 (at 50 m)	38.5-38.5 (at 50 m)	25.5-15.2 (at 50 m)	38.4-38.5 (at 50 m)
W. Peloponnisos	15-15 (at 30 m)	38.5-38.5 (at 30 m)	25-20 (at 30 m)	38.7-38.8 (at 30 m)
Thermaikos G.	9-14	29-38	29-15	35-38
Strymonikos G.	11-15	24-28	27-15	24-38
Pagasitikos	12.5-13.5 (at 50 m)	37-38 (at 50 m)	25-14 (at 50 m)	37.5-38.2 (at 50 m)
Maliakos G.	11.5-12 (at 20 m)	35-37.5 (at 20 m)	23-22 (at 20 m)	36.8-36.8 (at 20 m)
N. Evvoikos G.	13-12 (at 100 m)	36.8-37.5 (at 100 m)	28-14 (at 100 m)	37.6-37.8 (at 100 m)
Petalioi G.	11-14 (at 200 m)	38-39 (at 200 m)	24-13 (at 200 m)	37(5)-39 (at 200 m)
Saronikos G. (1)	12(2)-15	38-39	28(3)-13(4)	38-39
Kalloni G. (Lesvos)	11-9	36.2-38.2	26-17	41-39.2
Rodos coasts	17.7-16.9 (at 50 m)	39.1-39.2 (at 50 m)	27-19.5 (at 50 m)	39.3-39 (at 50 m)
Kriti (Irakleio Bay)	14.5-14.7 (at 100 m)	38.8-39 (at 100 m)	24.9-14.8 (at 100 m)	39.2-38.9 (at 100 m)
Standard Deviation	2-1.5	0.4-0.4	3-3	0.6-0.6

Source: *Based on CTD data from the Medar Group, 2002.*

Notes: *[1]: Including Elefsis Bay and the deep (450 m) west sub-basin*
[2, 3]: In Elefsis Bay [4]: In the west sub-basin [5]: Due to occasional inflow of Black Sea water

In winter, because of a higher volume input by the rivers compared with the summer, a higher exchange rate with the open sea is likely to occur and, therefore, a north-south salinity gradient can appear within the gulf with lower salinities in the north and higher in the south as opposed to the summer period. The interior of the gulf is always dominated by significantly lower salinity values with respect to the neighbouring sea outside the gulf and, therefore, the inside density is always lower than the outside at the same levels. As a result, dense water formation that would be accompanied by a vigorous flushing is not such a common phenomenon in the Amvrakikos as it is in the Gulf of Kalloni which is very shallow and receives only a minor freshwater input during winter (TSIRTSIS *et al.,* 2002). Figure III.5 shows near-bottom (12 m) distributions of salinity and density in the Gulf of Kalloni during summer (August 1994) and winter (February 1994). In summer the gulf is filled with highly saline water due to evaporation (salinity values exceeding 40.00). A lower salinity tongue is formed at the southeast of the gulf by lower salinity Aegean water that enters the gulf. In winter, some minor freshwater input into the gulf results in lower salinity values inside the gulf in comparison to the water outside, however, the density inside is much higher than the density outside because of intense cooling and the near-bottom layers outflow into the Aegean Sea (PAPADOPOULOS & KONTOYIANNIS, 1997).

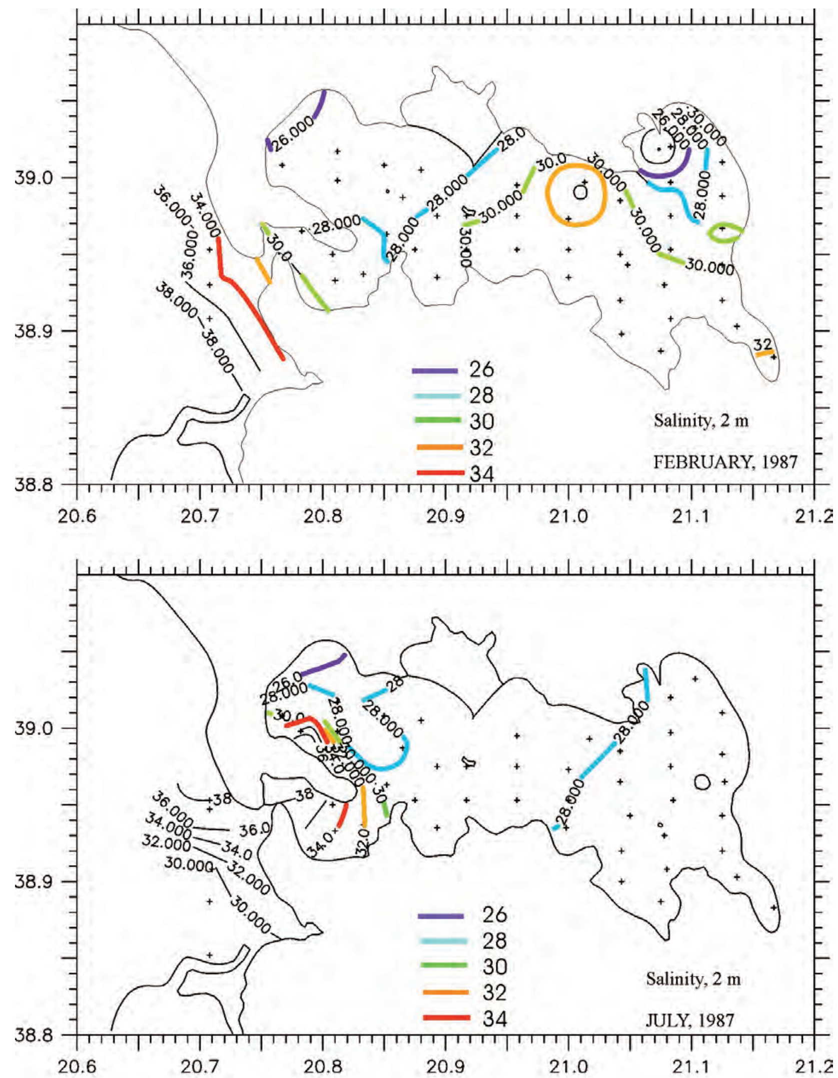
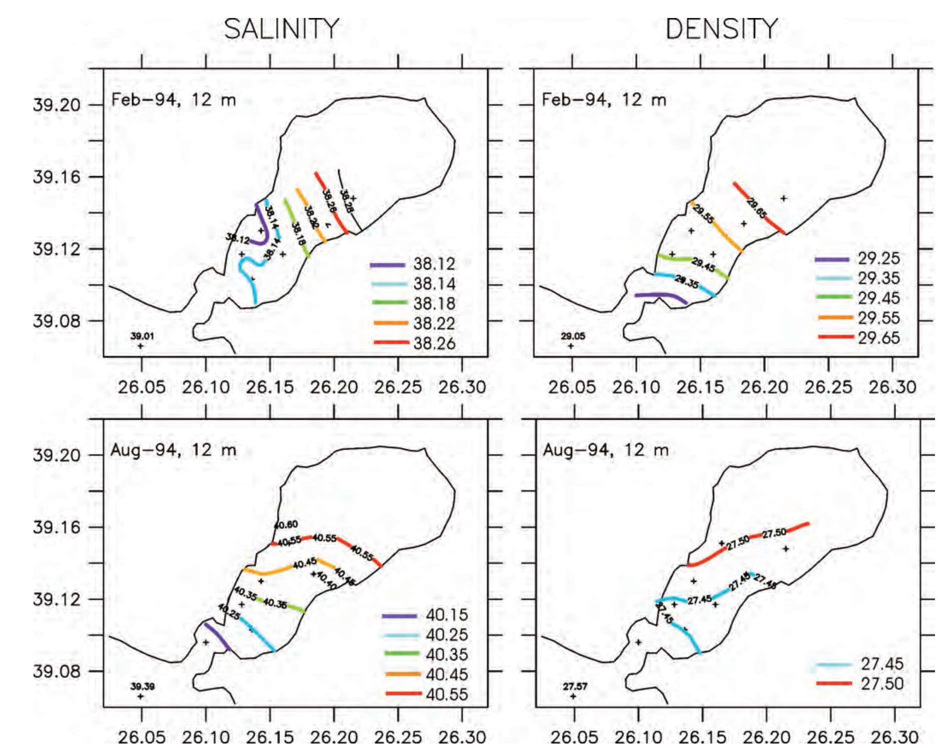


Figure III.4:
Surface salinity distributions in the Amvrakikos Gulf during winter (February 1987) and summer (July 1987).

Source: *BALOPOULOS & PAPAGEORGIOU, 1989.*

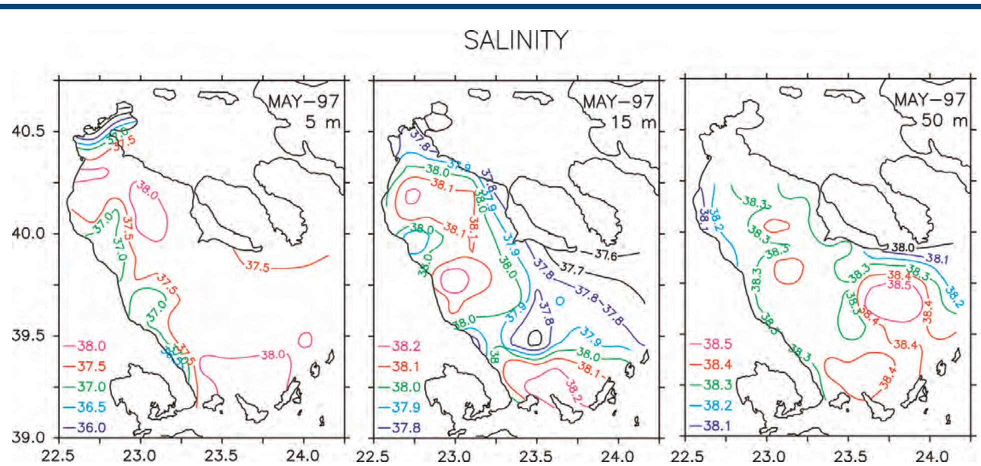
In coastal areas that are exposed to the open sea, water intrusions from the open sea are more critical in determining the local hydrodynamics. Figure III.6 shows salinity distributions at 5 m, 15 m and 50 m in the Thermaikos Gulf during May 1997.

In the surface distributions, salinity fronts are formed in the north part and along the west coast, where there is river water input (HYDER *et al.,* 2002). The central part of the entire elongated region is occupied by water masses of higher salinity which originate from lower latitudes in the Aegean, whereas the core of a lower salinity water mass that intrudes from outside the gulf exists at 15 m and 50 m at ~23.5˚ E ~39.6˚ N. In these upper layers



Source: *PAPADOPOULOS & KONTOYIANNIS, 1997.*

Figure III.5:
Salinity (left panels) and density (right panels) distributions in the Gulf of Kalloni during winter (February 1994, upper panels) and summer (August 1994, lower panels) at a near-bottom (12 meters) depth.



Source: *KONTOYIANNIS et al., 2003.*

Figure III.6:
Salinity distributions at 5 m (left panel), 15 m (middle panel) and 50 m (right panel) in the Thermaikos Gulf-Sporades Basin region during May 1997.

the water density is governed by salinity and we will see in the next section that the circulation is greatly influenced by the respective water mass distributions. A similar example is drawn from the Petalioi Gulf. Figure III.7 shows temperature, salinity and density distributions at 30 m in the Petalioi Gulf during September 1996. An intense cyclonic core, filled with water of lower temperature and higher salinity is observed in the Petalioi Gulf. In the particular field observations the mass and the flow fields of the study area in the Petalioi Gulf were mapped during seven consecutive two-day surveys. The observed cyclone was intensified during the sixth survey (R6) in parallel to the intensification of the south winds that were blowing during the respective period. The cyclone moved to the southwest and weakened after two days during the last field survey (R7) in September 1996.

CIRCULATION

Our knowledge of the circulation of Hellenic coastal areas is more limited than the corresponding knowledge on hydrological characteristics. In most cases the up-to-date knowledge on circulation has been inferred indirectly via the distribution of corresponding hydrologic characteristics and in fewer cases via the distribution of bottom sediments. There are only a few coastal areas in which the circulation has been investigated with direct current measurements having large spatial coverage capable to adequately map the existing flow structures. Even more limited information exists on the temporal current variability that is recorded from point current measurements. In the following we show a few cases of direct current observations on coastal flow structures, in addition to a tidal circulation example from the north Evvoikos Gulf.

Figure III.8 shows the circulation at 15 m during May 1997 in the Thermaikos Gulf. A large cyclone covers the shelf area that corresponds to the higher salinity denser water mass (Figure III.6) that covers this part of the gulf. Further south there is a dipole formed by a cyclonic and an anticyclonic structure of smaller scale, whereas north of ~40.35˚ N there is an even smaller anticyclone.

Figure III.9 shows flow structures in the Saronikos Gulf in the upper layer (20 m) and in the lower part of the thermocline (60 m) during a survey in August 1998. The Saronikos Gulf, as mentioned earlier, receives no major fresh-water input from rivers, but it receives the treated waste of the entire Athens metropolitan area through a point source that discharges at the sea bottom at 65 m south of the small island of Psittalia in the northeast part of the Gulf. The bottom of the eastern part of the gulf is relatively flat with a mean depth of 90 m and with the 100 m isobath located to the east of Aegina Island. In the western part, which is deeper, there is an elongated north-south trough with maximum depths around ~200 m in the north and ~450 m in

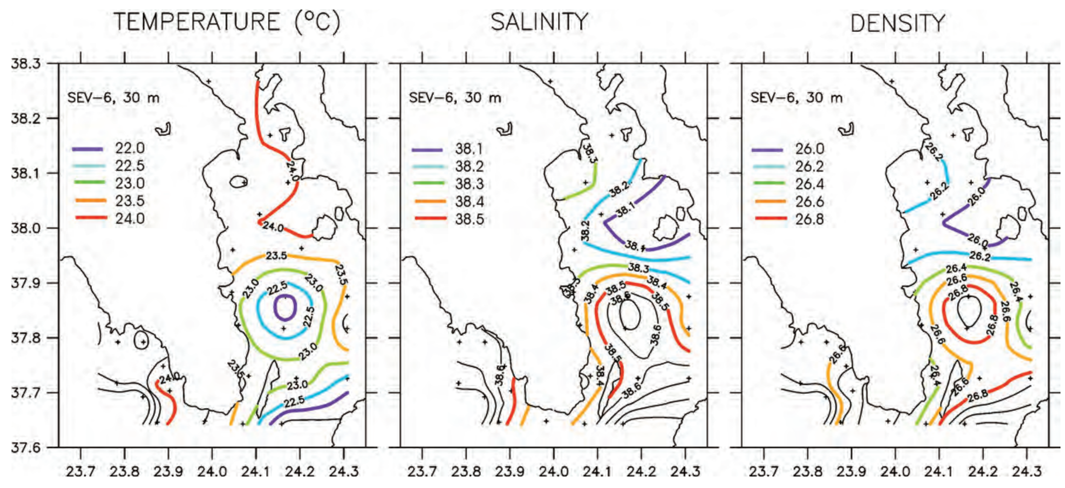
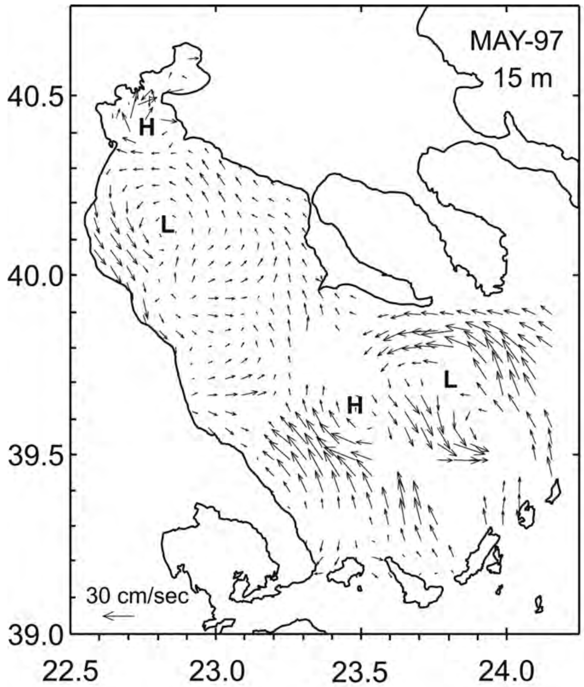


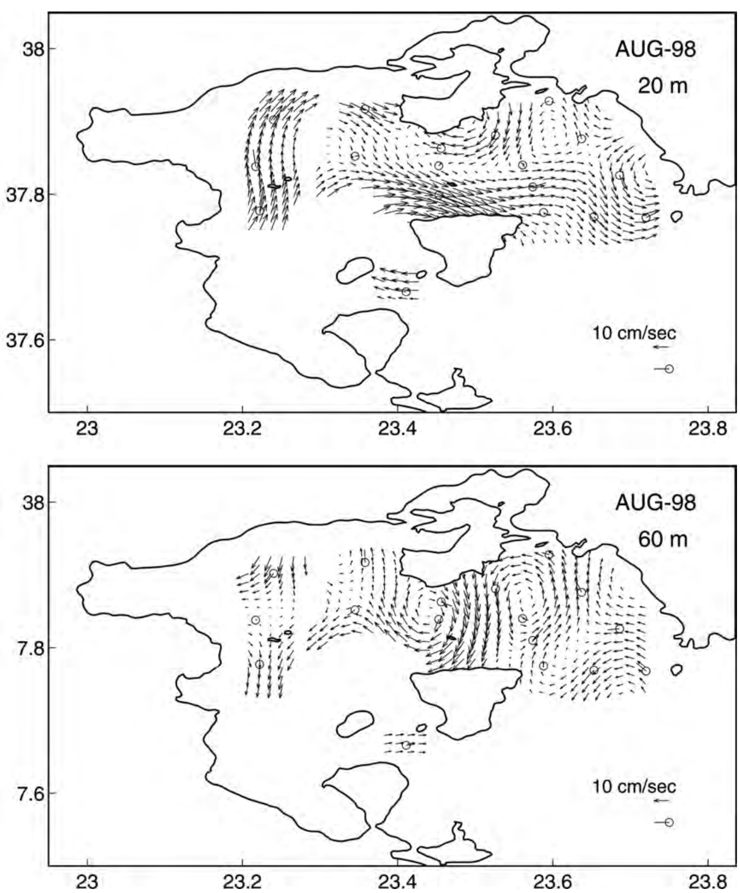
Figure III.7: *Temperature (left panel), salinity (middle panel) and density (right panel) distributions at 30 m during 16th and 17th September 1996 in the Petalioi Gulf.*

Source: *KONTOYIANNIS & PAPADOPOULOS, 1996.*



Source: *KONTOYIANNIS et al., 2003.*

Figure III.8:
Objectively-interpolated current vectors at 15 m in the Thermaikos Gulf and Sporades Basin during May 1997. Blank areas correspond to objective mapping errors greater than 70%.



Source: *KONTOYIANNIS & PAPADOPOULOS, 1999.*

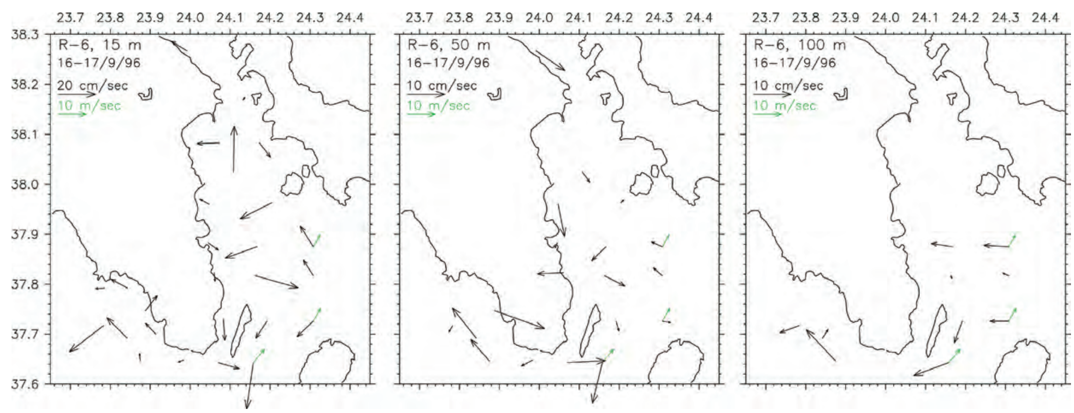
Figure III.9:
Objectively-interpolated current vectors (arrows) plotted versus raw measurements (sticks with circles) at 20 m (upper panel) and 60 m (lower panes) in the Saronikos Gulf during August 1998. Blank areas correspond to objective mapping errors greater than 70%.

the south. The circulation in the Saronikos Gulf has been reported to be very strongly dependent on the local wind and is of particular significance in view of the transport of pollutants coming from the sewage treatment plant outflow at 65 m in the northeast. The limited number of direct current observations, shown in Figure III.9 with circles, have been interpolated through objective analysis and indicate that there is a flow from the northeast to the southwest which in the deeper layer is continued anticyclonically in the west sub-basin. This flow structure was observed after and during northerly winds. More details on flow structure(s) have been revealed after 1998 by direct current observation on a dense station grid focused on the eastern part, but only in the context of single, quasi-synoptic non-consecutive snapshots (KONTOYIANNIS & PAPADOPOULOS, 1999).

The direct current observations depicting the cyclonic eddy that was developed in the Petalioi Gulf in September 1996 are shown in Figure III.10. The eddy was well defined in the upper ~50 m. It had a strong vertical shear and it virtually faded out below 50 m. At 100 m depth there was a general cyclonic flow, which roughly followed the bottom contours.

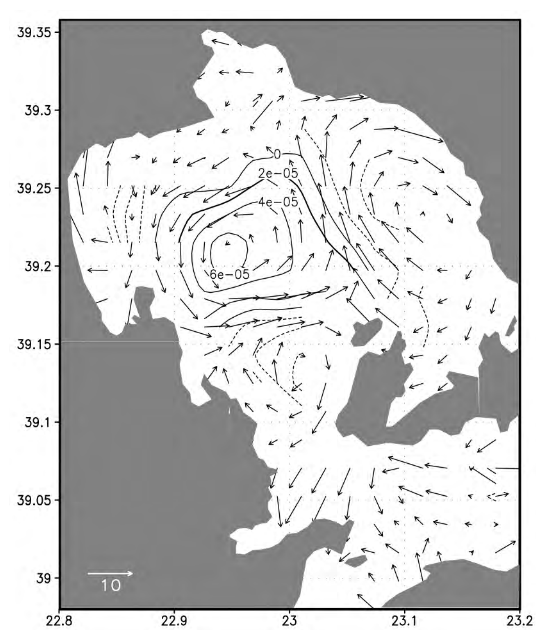
Figure III.11 shows direct current observations in the Pagasitikos Gulf during July 1999. This rather enclosed water body has a mean depth of 69 m

Figure III.10: *Current flow vectors (black arrows) at 15 m (left panel), 50 m (middle panel) and 100 m (right panel) during the 16th and the 17th of September 1996 in the Petalioi Gulf. Green arrows represent wind measurements during the same period.*



Source: *KONTOYIANNIS & PAPADOPOULOS, 1996.*

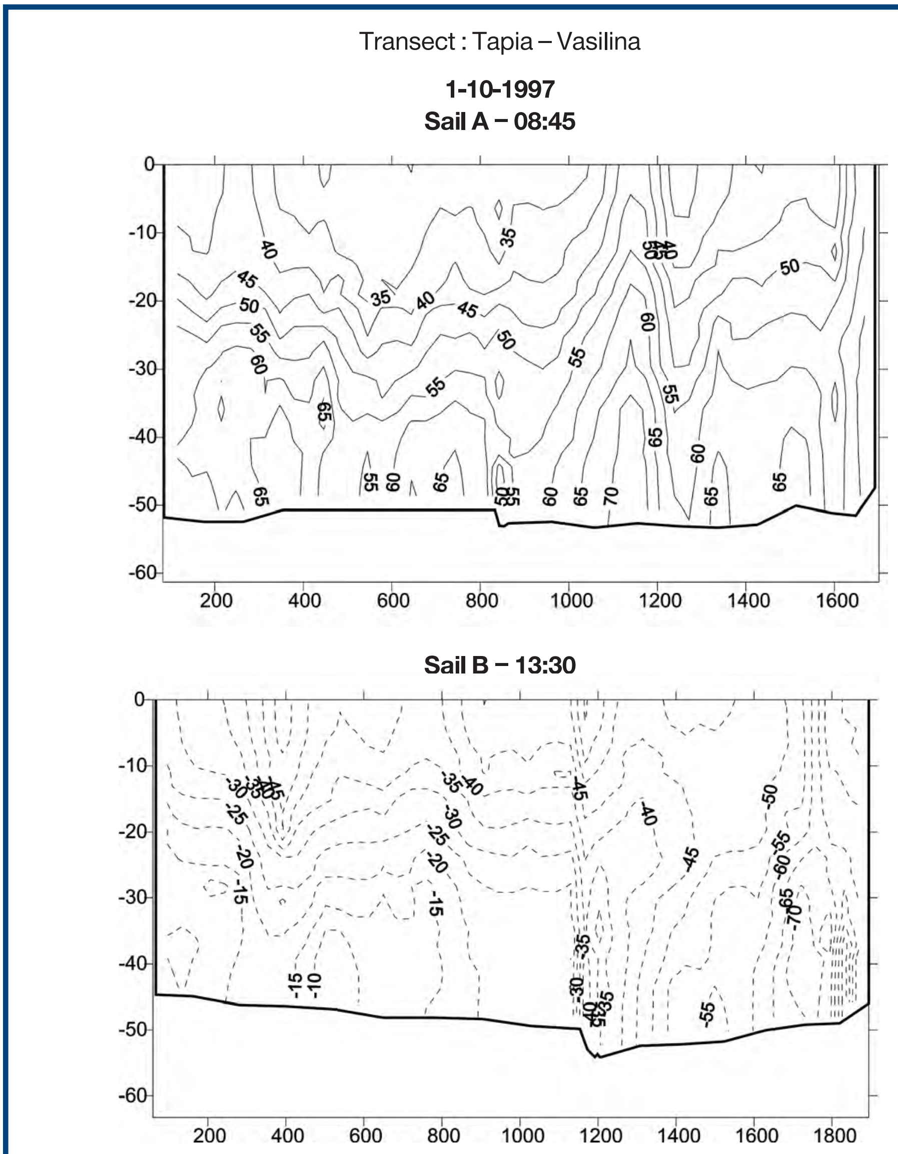
Figure III.11: *Objectively-interpolated surface velocity field in the Pagasitikos Gulf during July 1999.*



Source: *PETIHAKIS et al., 2002.*

while the maximum depth is 108 m at its eastern part. In the Pagasitikos Gulf the wind is considered to be the main forcing of the circulation. The circulation pattern in the southern (outer) area of the gulf is rather complex as it is determined by wind action, water mass exchange with the Aegean Sea and the tidal movements in the north Evvoikos Gulf. On the other hand, the dynamic behaviour of the inner gulf (central and northern part) depends on the wind. Although the circulation patterns are usually transient, in the case of the Pagasitikos there is an almost stable dipole, an anticyclone in the east and a cyclone in the central – west, accompanied by smaller jets and eddies.

In the narrow straits between the island of Evvoia and the Hellenic mainland the tidal effect on the flow is dominant over the sub-tidal flow components and is also easily observed through simple visualisation without current meters. Figure III.12 shows the flow through the Oreoi Channel, i.e., normal to a northwest-to-southeast transect from the Hellenic mainland to Evvoia at a location west of the south entrance of the Pagasitikos Gulf. The upper panel depicts the flow during ebb (1st October 1997 around ~08:45 local time) when the current flows to the northeast out from the north Evvoikos Gulf. The lower panel shows the flow through the Oreoi Channel during flood (1st October 1997, around ~13:30 local time) when the flow has reversed towards the southwest (KRESTENITIS, 2000).



Source: *KRESTENITIS, 2000.*

Figure III.12:
Transects of current speeds in cm/sec normal to the northwest to southwest transect between the Hellenic mainland (on the left) and Evvoia (on the right) (see text) during 1st October 1997. Solid/dashed contours (positive/negative speed values) denote flow to the NE/SW during ebb/flood occurring around 08:45/13:30 and shown in the upper/lower panel.

III.2. CIRCULATION AND HYDROGRAPHY OF THE OPEN SEAS

The circulation in several basins surrounding the Hellenic Peninsula (i.e. the Aegean, Ionian and Levantine seas) is partly determined by the general circulation of the eastern Mediterranean Sea and partly by local interaction with the atmosphere and bottom topography. In order to assess the various circulation components, one has to define the spatial and temporal scales of the circulation features.

THERMOHALINE CIRCULATION

Thermohaline circulation of the Eastern Mediterranean Sea

In the largest scales of interest, i.e. interannual and basin-wide scales, the circulation of the eastern Mediterranean Sea is determined by its exchanges of water and heat with the atmosphere through the sea surface. The circulation forced by the buoyancy exchanges of the sea with the atmosphere is called thermohaline and it usually reflects the largest scale motions of the sea. As a semi-enclosed basin, the eastern Mediterranean Sea is classified as a concentration or lagoonal basin (i.e. a semi-enclosed basin where high-density water is being produced). This conclusion can be reached either by checking that its fresh-water and buoyancy budgets are negative over periods larger than a year (as explained in Chapter II.1), or by comparing the densities of the deep waters of the eastern Mediterranean Sea to those of the western Mediterranean Sea (HOPKINS, 1978). Being a concentration basin, the eastern Mediterranean Sea receives light waters at the surface and exports dense waters by underwater currents to the western Mediterranean and the Black Sea through the connecting straits, the Strait of Sicily and the Dardanelles respectively.

A simplified depiction of the thermohaline circulation of the Eastern Mediterranean is presented in Figure III.13. Estimates of the inflow of surface waters originating in the Atlantic (known as the **A**tlantic **W**ater (**AW**) mass) through the Strait of Sicily to the eastern Mediterranean Sea range from 20 000 km^3 to 40 000 km^3 annually. The corresponding outflow of intermediate waters originally formed in the eastern Mediterranean, namely the **L**evantine **I**ntermediate **W**ater (**LIW**) is estimated to range from 18 000 km^3 to 38 000 km^3. The AW inflowing through the Strait of Sicily, characterised by low salinities (having been modified in their westward flow along the African

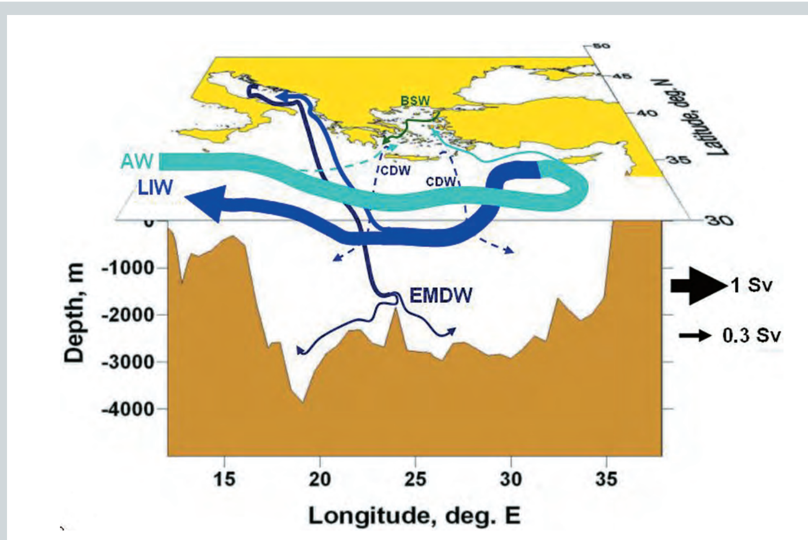


Figure III.13
Pre-1987 thermohaline circulation of the Eastern Mediterranean. The arrow thickness denotes transport in Sverdups (1 Sv = 106 m^3 s^{-1} ~31500 km3 yr^{-1}).

coast by mixing and air-sea interaction), occupies a 150-200 m thick layer in the Ionian Sea. The thickness of this surface layer diminishes as it flows eastwards. The salinity minimum in the water column, which is the signature of AW, is found mostly at about 50 m during summer and near the surface during winter. The salinity of AW increases from about 36.8 at Gibraltar, to approximately 37.5 psu in the Strait of Sicily area to 38.6 psu near the Cretan Passage and the depth of the AW core increases eastwards (from 20 to 100 m) during summer and autumn. The AW continues its eastward route reaching the easternmost Levantine at 38.9 psu. The same salinity is mostly detected in the AW that often enters the Aegean through the Straits of the Arc of Kriti.

The corresponding exchange with the Black Sea amounts to surface inflow of about 1 250 km^3 yr^{-1} of **B**lack **S**ea **W**ater (**BSW**) and deeper outflow of about 950 km^3 yr^{-1} of Aegean water through the Dardanelles (ÜNLÜATA *et al.*, 1990). The Black Sea-originated waters, being much less in quantity than the Atlantic Water, form a distinct water mass (BSW) that is traceable as a salinity minimum at the surface only in the north and western Aegean Sea until the Kythira Strait. The surface salinity of BSW waters can be as low as 29-30 psu in the immediate vicinity of the Dardanelles in summer conditions of maximum stratification. Through dispersion in the north Aegean the BSW salinity reaches 35-36 over the North Aegean Trough. In the winter higher salinity values are recorded, due to increased mixing with the underlying Levantine water layer. The waters outflowing towards the Black Sea through the Dardanelles have a salinity of about 38.

Thus, at both the Sicily and Dardanelles Straits, the eastern Mediterranean imports light waters at the surface and exports dense waters at a subsurface layer, thus operating as an engine producing dense waters (using terminology from engineering). Indeed, such a circulation at the straits requires that the light waters entering the sea, gain density and sink deeper at some point in their path, forming the dense waters that eventually exit the sea through the undercurrents of the straits. The mechanism of sinking requires that the light, surface waters become colder (by losing heat into the atmosphere) and/or saltier (by losing fresh water through evaporation) and thus become heavier than the waters immediately below them. Thus, the flow of water and exchange through the straits is accelerated when the loss of heat and vapour from the surface waters increases and more dense water is produced. This process, namely the dense water formation, is thus considered the driving engine of the thermohaline circulation of a semi-enclosed sea, or the motor setting the thermohaline 'conveyor belt' in motion. In the world ocean, the main areas of dense water formation are located near the poles, where vast heat losses into the atmosphere contribute to the formation of very cold and dense water that sinks towards the sea bottom.

The interannual variability of the eastern Mediterranean's thermohaline circulation and especially regarding the areas where exceptionally dense water is formed at the surface and sinks all the way to the bottom is addressed in the following chapter. One of the main reasons that the Mediterranean Sea has often been named by oceanographers as a mini-ocean or a natural geophysical laboratory is that, unlike other semi-enclosed basins, it possesses its own conveyor belt (Chapter III.3). The sites where the deep water of the eastern Mediterranean is formed are the two northern extremities of this basin namely, the Aegean and Adriatic Seas (Figure III.13). Recent developments have shown that both sites have the potential to contribute to the waters filling the deep Ionian and Levantine basins (deeper than 2 000 m, down to the bottom). These waters comprise the **E**astern **M**editerranean **D**eep **W**ater (**EMDW**) water mass, which is formed in the Ionian Sea through the mixing of the intermediate waters with mainly the deep cold and dense winter Adriatic waters outflowing through the Otranto Strait. The EMDW has been considered remarkably uniform at 13.3 °C in temperature and 38.7 psu in salinity for very long periods (1910-1987). At least once in the last century the Aegean Sea has contributed substantially to the deep waters of the eastern Mediterranean Sea altering the deep conveyor belt and slightly changing the deep-water characteristics (Figures III.25a and b in Chapter III.3).

Perhaps of even greater importance to the thermohaline circulation and water-column structure of the eastern Mediterranean Sea is the formation of intermediate waters. A great quantity of surface waters entering the Ionian Sea through the Strait of Sicily, never reach the dense water formation areas of the Mediterranean. During their eastward journey, evaporation deprives them of significant quantities of water and their salinity rises from less than 38.5 near the Sicily Strait to more than 39.1 in the region south/southwest of Asia Minor. In that region, excessive evaporation and heat loss, combined with a dominant cyclonic water circulation (induced by the wind-curl), provide favourable conditions for the formation of large amounts of highly saline, warm water that sinks to an intermediate depth, down to 600 m and comprises the largest water type of the eastern Mediterranean, namely the LIW (Figure III.13). The LIW is considered the most important component in the Mediterranean's large-scale circulation because it spreads throughout the entire Mediterranean and affects the background stratification at the areas of dense water formation. It is generated primarily in the northern Levantine Basin and more specifically to the southeast of Rodos Island in February and March under the influence of dry and cold continental air masses. A dominant cyclonic circulation southeast of Rodos, namely the Rodos gyre, plays an important role in the formation and spreading of LIW. LIW is found mostly in a thick subsurface layer. Its core depth fluctuates from 50 m in cyclones to 600 m within the strong anticyclones. It overlies the colder and less saline EMDW. Therefore, its signature is a maximum in salinity, which is found mostly in the subsurface layer; and also at the surface in the formation areas during formation periods. The hydrological characteristics of the source waters generated at different regions vary (T~14.70-16.95 ˚C, S~38.85-39.15 and density ~ 28.9-29.1 kg m^{-3}), (GEORGOPOULOS *et al.*, 1989). As LIW spreads westward, homogeneity is achieved and loss of heat and salt occurs due to mixing processes.

Thermohaline circulation of the Aegean Sea

The thermohaline circulation in the Aegean Sea is a subject as complex as that of the eastern Mediterranean Sea. The Aegean Sea is characterised by extremely high densities in its deep sub-basins, with the most dense waters found in the deep basins of the north Aegean, a fact suggesting that the Aegean is itself a concentration basin and that this character is intensified in the north, i.e. that the north Aegean is a source of more dense water than the south Aegean. The thermohaline circulation of the Aegean Sea is summarised in Figure III.14.

However, the fresh-water and buoyancy budgets of the north Aegean suggest that on seasonal and larger time-scales this basin behaves as a dilution basin, i.e. as an exporter of light waters to the south Aegean, due to the contribution of the light, brackish waters of the Black Sea through the Dardanelles Strait. These waters, entering the north Aegean to the east of the island of Limnos, form a thin (20-40 m thick) surface layer that expands all over the north Aegean Sea, following a cyclonic flow towards the west and southwest. This layer isolates the intermediate waters from the atmosphere, having the capacity to lose great amounts of heat and water before attaining a density equal to that of the underlying layer and to stop hindering dense water formation (ZERVAKIS *et al.*, 2000). On an annual time-scale, the buoyancy input from the Dardanelles is balanced by some buoyancy loss to the atmosphere and the export of light waters to the south Aegean, thus the net thermohaline role of the north Aegean is that of a dilution basin.

However, on monthly time-scales, the north Aegean may act as a strong concentration basin, as the density distribution in the deep basins throughout the Aegean Sea suggests. Indeed, the waters filling the deep basins of the north Aegean (up to the 400 m sill-level) are characterised by densities at least 0.20 kg m^{-3} higher than the water mass filling the deep sea of Kriti, namely the Cretan Deep Water (CDW).The extended shelves of the

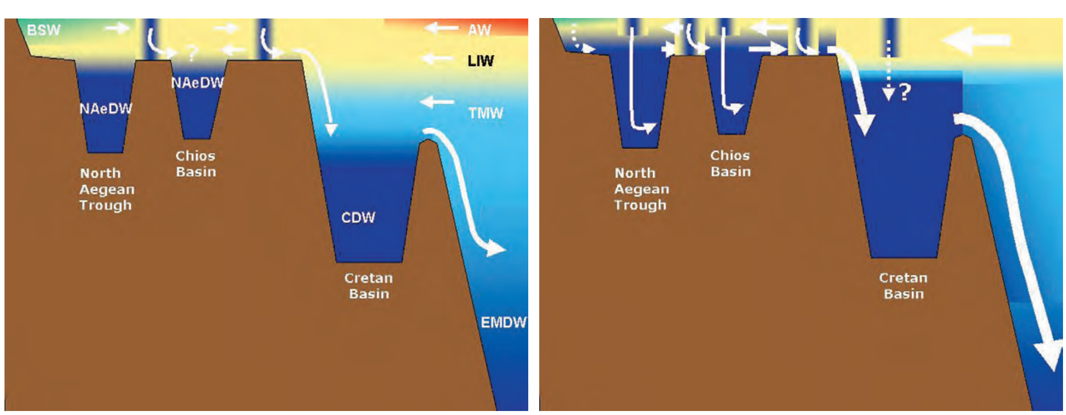


Figure III.14 *Schematic thermohaline circulation of the Aegean Sea during mild periods (left) and periods of massive dense water formation (right).*

Samothraki Plateau, the Thermaikos Gulf, the shelves of Lesvos and the Kyklades islands are ideal sites of dense water formation, due to the limited volume of water exchanging buoyancy with the atmosphere. However, dense water formation in the Samothraki Plateau and Thermaikos Gulf is hindered by the isolating action of the surface BSW layer and river outflow (especially in the latter case). Comparing the shelves of Lesvos and the Kyklades, it is evident that the former has a higher potential for dense water formation for two reasons: (i) the cyclonic circulation of the Aegean Sea brings highly saline waters (having undergone high amounts of evaporation throughout their journey from the south Aegean and the Levantine) to the region, while the Kyklades shelf is significantly influenced by the extent of the southern limits of the BSW layer of the north Aegean, and (ii) the cold northerlies are drier in the north Aegean than in the Kyklades due to the proximity to land, thus causing higher evaporation in the northern shelves. Observations suggest that both sites exhibit dense water formation annually, however, the relative importance of the two regions as the engine of the Aegean's thermohaline conveyor belt has not been determined yet quantitatively.

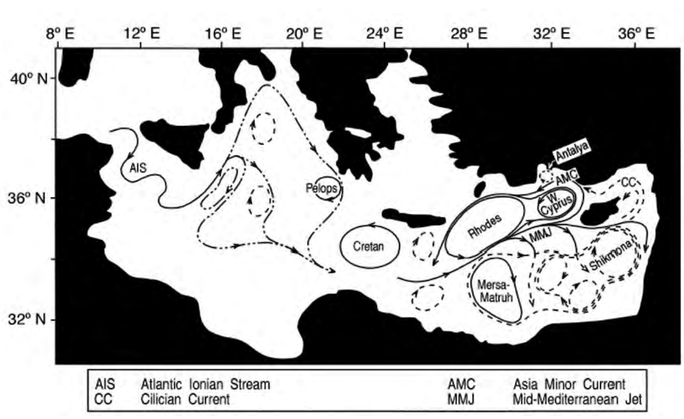
The buoyancy budget of the south Aegean suggests that it is clearly a concentration basin, in terms of the buoyancy exchanges with the atmosphere and the rivers. However, when considering the buoyancy inflow from the north Aegean, the budget may get altered sporadically.

Overall, the outflow from the Aegean, whether it is surface, light waters or dense waters, is balanced through the inflow of LIW and its mixture with EMDW, namely, **T**ransitional **M**editerranean **W**ater (**TMW**) through the Straits of the Cretan Arc. The LIW water mass in the Cretan Sea is occasionally characterised by higher oxygen/higher salinity than outside the Arc Straits of Kriti and then it is identified in the literature as **C**retan **I**ntermediate **W**ater (**CIW**); however, for the purposes of this review, we will not focus on the differences between the two water types. The CIW/LIW water mass is identified by its salinity maximum (reaching 39.2 psu); it fills the intermediate layers (100-400 m) of the north Aegean, separating the BSW surface layer from the locally formed North Aegean Deep Waters. In the south Aegean, this layer overlies a layer of TMW imported through the Arc Straits of Kriti (identified by a salinity minimum, dissolved oxygen minimum and nutrient maximum) and the Cretan Deep Water. The main origin of CDW is considered to be the Kyklades Plateau, with a possible contribution from north Aegean deep waters during periods of massive dense water formation in the north Aegean, as shown in Figure III.14b (ZERVAKIS *et al.*, 2000). The surface layers of the Cretan Sea are occupied by a warm, highly saline layer often referred to as Cretan Surface Water (CSW). Occasionally, Atlantic water can be traced in the southwest and southeast Cretan Sea entering through the Arc Straits of Kriti.

SUB-BASIN SCALE CIRCULATION

Ionian and Levantine Seas

The Ionian dynamic structure of the sub-basin scale circulation before 1987 as recorded during the POEM program consists of a meandering jet and numerous cyclonic and anticyclonic gyres and eddies (Figure III.15) (The POEM group, 1992;



Source: *MALANOTTE-RIZZOLI, 1997.*

Figure III.15:
Surface circulation of the Eastern Mediterranean.

MALANOTTE-RIZZOLI *et al.*, 1997). The North African Current, advecting the AW into the basin interior, enters the Sicily Strait forming the **A**tlantic **I**onian **S**tream (**AIS**) jet that bifurcates into two main branches. Its first branch encloses an anticyclonic area in the central Ionian, comprising multiple centres, namely the **I**onian **A**nticyclones (**IA**). The second branch extends further to the north then it turns southwards crossing the entire Ionian meridionally, advecting AW on its left side and **I**onian **S**urface **W**ater (**ISW**) on its right. Then, this jet meanders further eastward forming the **M**id-**M**editerranean **J**et (**MMJ**) crossing the Cretan Passage carrying AW to the east.

The above circulation changed significantly during the period extending from the late 1980s to the late 1990s, resulting in a decrease of AW input into the Aegean and Levantine basins and the subsequent rise of salinities in these areas (MALANOTTE-RIZZOLI *et al.*, 1999). This change is addressed in detail in Chapter III.3.

Moreover, two basic characteristic gyres develop in the eastern Ionian (i) the deep barotropic ***'Pelops' anticyclonic gyre*** to the SW of the Peloponnisos and (ii) the large ***'Cretan' cyclone*** to the southwest of Kriti, both presenting high spatial variability (THEOCHARIS & KONTOYIANNIS, 1999). The warm and saline Levantine Surface Water (LSW) that forms in the Levantine basin circulates around the two above mentioned gyres, then occasionally entering the Aegean through the western Arc Straits of Kriti.

Some of the characteristic gyres of the Levantine basin are the permanent cyclonic Rodos Gyre, mainly responsible for the formation of LIW waters, the Mersah-Matruh anticyclone, the Shikmona and Cyprus gyres in the eastern Levantine basin. One anticyclone of the Levantine basin, characterised by its almost perfectly circular shape and recurrent nature, is the ***Ierapetra anticyclone***, forming to the southeast of Kriti (Figure III.15)

Aegean Sea

The surface circulation of the Aegean Sea is quite well understood today, as a consequence of the various international, European and national research projects, and regional studies performed in the region. Our current knowledge of the surface circulation is summarised in Figure III.16.

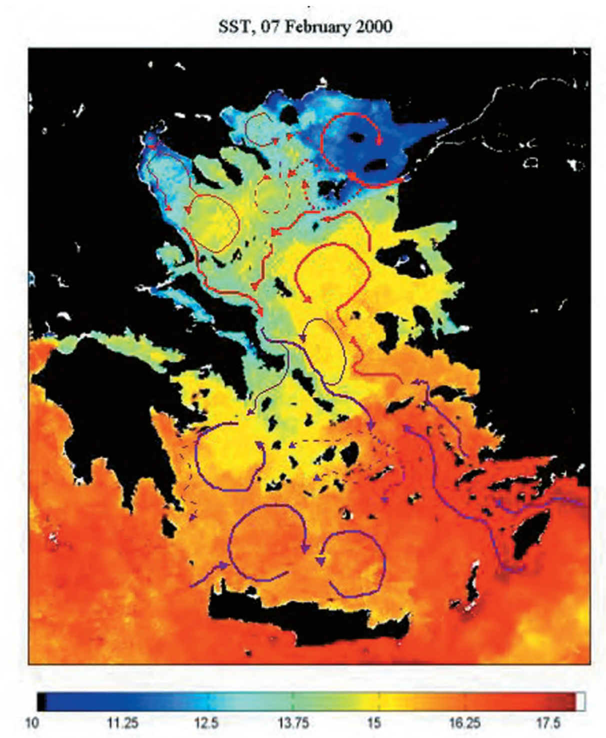


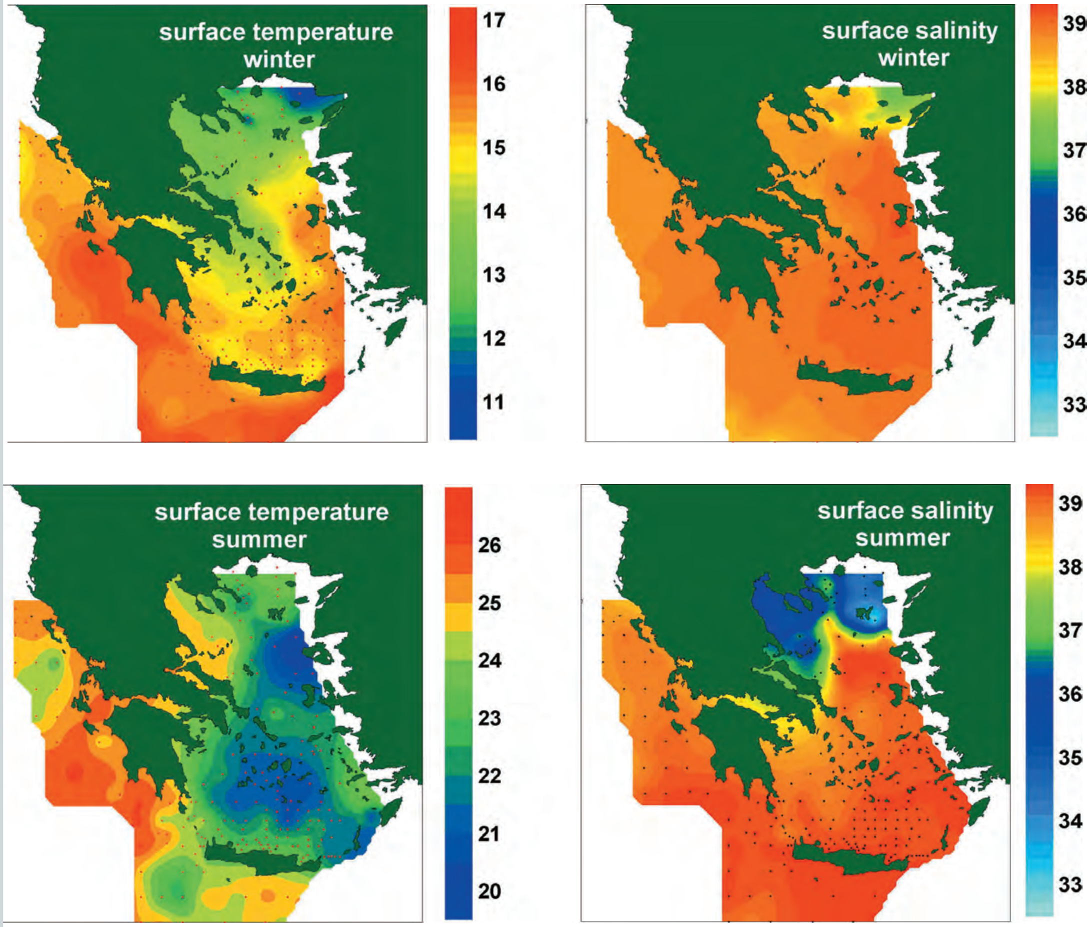
Figure III.16
Surface circulation of the Aegean Sea (arrows) superimposed on a sea surface temperature image from satellite (Solid lines represent permanent features and dashed lines recurrent or transient features).

In general, the circulation in the Aegean Sea is cyclonic, with warm, saline water from the Levantine entering the Aegean through the eastern Cretan Straits via the branches detached from the AMC. This Levantine water mass travels northwards along the eastern Aegean Sea. The Chios basins in the central Aegean are dominated by two permanent cyclones, which contribute to this general cyclonic circulation. The Levantine waters, when reaching the Black Sea outflow in the vicinity of the island of Limnos, get subducted below the very light Black Sea water layer. This layer is formed by waters flowing out from the Dardanelles and then moving westwards and eventually southwards. It covers the north Aegean and moves in a cyclonic motion westwards and southwards along the east coast of the Hellenic Peninsula. Occasionally, part of the low-salinity water is arrested by a permanent anticyclone flowing around the island of Samothraki, forming a salinity minimum there. This anticyclone is also responsible for the southward dispersion of the river Evros plume. The low-salinity surface waters of the Samothraki Plateau form a thermohaline front with higher salinity waters along the Athos – Limnos Strait. The exchange across the front appears to be a partly barotropic (over the Samothraki Plateau) partly baroclinic (over the North Aegean Trough) response to the variability of the meridional sea surface pressure gradient along the Aegean Sea (GEORGOPOULOS, 2002). Under certain conditions, the front 'breaks' and a cyclone is formed off Athos, carrying water from the plateau southwards, while water of higher salinity flows northwards west of Limnos island, often generating a mushroom-like feature. The North Sporades basin is characterised by variable mesoscale circulation and the recurrence of a cyclone over the deep basin.

The cyclonic circulation of the north and central Aegean, characterised by the northward flow of Levantine waters along the eastern Aegean, culminates in a very strong, permanent return south-eastward current along the east coast of the island of Evvoia. This flow is continued along the northern edge of the Kyklades archipelago and partly feeds the cyclone of Chios basin. A small part of the Evvoia current crosses the Cavo D'Oro channel and flows south-westward to enter the Myrtoan Sea and feeds a permanent or recurrent cyclone there. However, the circulation in the Cretan Sea is currently dominated by the presence of an anticyclone over central/western north Kriti and a cyclone over central/eastern north Kriti. The two features form a dipole, largely barotropic, which has been observed repeatedly in the Cretan Sea since 1994.

SEASONAL VARIABILITY OF HYDROGRAPHIC FEATURES

The circulation of the Aegean Sea exhibits small variability at synoptic scale, as a response to atmospheric variability. The reason for this is that the circulation is largely determined by baroclinicity and topography; thus, it is characterised by a cyclonic circulation of the Black Sea waters from the northeast Aegean and of the Levantine waters from the area of Rodos. This circulation is reflected in the surface distribution primarily of salinity observed through most of the year (Figure III.17). The sea surface temperature also exhibits the same distribution in winter. However, on a seasonal time-scale, there is a very major change in the Aegean Sea circulation, which may be playing a significant role, not only in influencing the longer-term hydrographic properties of the Sea, but also in affecting its ecosystem. This change, that takes place annually in the Aegean, is the coastal upwelling of intermediate waters, evidenced every summer along the eastern Aegean, as a response to the persistence of the Etesian northerly winds during the months of July and August. The Etesians displace the warm, surface waters towards the western Aegean, due to the rotation of the earth. These waters are replaced by intermediate, cool waters that rise to the surface. Thus, every summer, the dominant annual zonal temperature gradient, reflecting the path of the Black Sea waters, is replaced by a meridional gradient mirroring the upwelling of intermediate waters along the eastern Aegean Sea (Figure III.17). The oligotrophic character of the Aegean limits the importance of the coastal upwelling (in comparison to coastal upwelling sites of the open ocean) however, the ecological importance of the seasonal upwelling in the eastern Aegean remains to be studied.



Note: The scales in the temperature plots are different.

Figure III.17: *Typical winter and summer temperature (left) and salinity (right) as recorded in the framework of the POEM program.*

III.3. LONG TERM WATER MASSES: TIME SCALES

THE BASIC FUNCTIONING

The Mediterranean Sea is an elongated and relatively narrow basin, bounded by the European and the North-African coasts. It is a semi-enclosed basin, which communicates with the rest of the world's oceans through the narrow (~15 km) and shallow (sill depth ~250 m) Straits of Gibraltar. The Straits of Sicily (sill depth ~1 000 m) divide the basin into two major sub-basins, the western and the eastern Mediterranean Sea respectively. In each of these, a number of smaller basins or seas can further be found such as the Balearic and Tyrrhenian seas in the west and the Adriatic, Ionian, Aegean and Levantine seas in the east. In the Mediterranean, evaporation exceeds precipitation and river runoff. It is what is termed a 'concentration' basin. Because of the communication with the Atlantic Ocean through the Straits of Gibraltar, a dynamic equilibrium is established through a two-layer flow in the straits. Lower salinity Atlantic waters enter the Mediterranean at the surface, where they are transformed through evaporation into saltier (and denser) Mediterranean waters, then sink to an intermediate depth and move back to Gibraltar where they are exported into the Atlantic. An equilibrium is, therefore, reached by which the salinity of the basin remains constant. This type of circulation with water entering the basin at surface and exiting at depth is called a 'lagoonal' circulation. In basins, such as the Black Sea, where precipitation and river runoff exceed evaporation ('dilution' basins) an opposite type of circulation is usually established with fresher water exiting the basin at surface and a smaller amount of saltier water entering the basin at depth ('estuarine' circulation). These two circulation types, by which a semi-enclosed basin maintains its salinity, whether it is a concentration or a dilution basin, have far-reaching and important consequences. In the first case, the deeper layers of the basin are naturally oxygenated through the sinking of surface water, which is in contact with the atmosphere and is saturated in oxygen. This explains the high oxygen content of the Mediterranean Sea throughout the water column. On the contrary, in the second case the deeper layers of the basin are isolated from the atmosphere and have a very low or even zero oxygen content. This is, for example, the case in the Black Sea, where anoxic conditions are found just below the surface fresh water layer. These anoxic conditions are 'natural' and are not in any way pollution-related. Therefore, we can think of the Mediterranean as a basin that, through interaction with the atmosphere (evaporation), transforms fresher (salinity 36.5 psu) Atlantic surface waters into saltier Mediterranean waters, which are then sent back to the Atlantic at depth. This is the simplest way (or the simplest model) to look at the functioning of the Mediterranean. Of course, the Mediterranean is much more complicated than that.

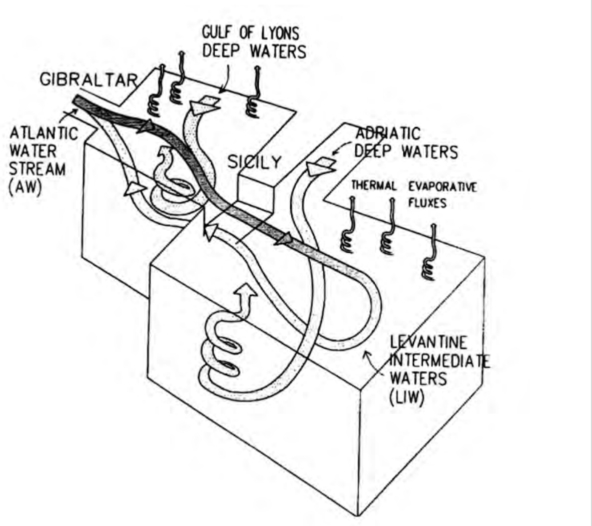
DEEP AND INTERMEDIATE WATERS

In winter, over the whole basin, surface cooling increases the density of the surface waters, which become unstable and sink. This sinking homogenises the surface layers and produces what is called the 'winter mixed layer'. The thickness of the winter mixed layer is of the order of 50 to 100 m. In some very well defined locations and because of specific conditions that prevail in these areas, winter cooling is very violent and the vertical mixing called 'convection' can penetrate to intermediate depths of a few hundred metres or even down to the bottom. These areas are the so-called 'sources' of intermediate or deep waters. The conditions mentioned above are related to the existence of strong, cold and dry winds of the northern sector, as well as some favourable conditions regarding the hydrological characteristics of the sea, such as the existence of a cyclonic circulation in the area. There are two sources of deep (Gulf of Lions and southern Adriatic) and one of intermediate (Rodos Gyre) waters in the Mediterranean Sea. The deep waters of the western and eastern Mediterranean Sea are confined in the deepest parts of the respective basins because of the sills at Gibraltar and Sicily. In contrast, the LIW sink to depths of only 200-400 m. They then start a long journey to the west, enter the Ionian, then the western Mediterranean through the Strait of Sicily and finally exit to the Atlantic through Gibraltar. They are the main contributor (more than 80 %) to the outflow into the Atlantic where they can be traced as far as Greenland. The main characteristic of the LIW is their high salinity since they originate from the Levantine, an area where strong evaporation occurs. Their salinity is 39.00-39.05 psu at the formation site. It decreases through mixing along their journey and by the time they reach Gibraltar it is 38.4 psu. On a mean annual basis 0.3 Sv (1 Sv = 106 m^3/sec) of deep waters are formed at each of the two sites while the production rate for the intermediate waters is estimated to be 1-1.5 Sv (LASCARATOS, 1993). A fraction of only 4% of the total LIW present in the Mediterranean Sea is produced annually. In other words, a water particle of LIW formed this year will need approximately 25 years to reach Gibraltar and exit the Mediterranean. For the deep waters, this time scale is of the order of 80 to 100 years. The circulation of the deep and intermediate waters inside the basin, the so-called ‘thermohaline circulation’, is much slower than at surface (Figure III.18).

THE EASTERN MEDITERRANEAN TRANSIENT

The Adriatic Sea has been historically considered the main contributor to the deep and bottom waters of the entire eastern Mediterranean Basin resulting in an almost horizontally homogeneous temperature and salinity values in the Ionian and Levantine basins (Figure III.19). However, the Aegean has been reported as a possible secondary but sporadic source of dense waters. These relatively warmer and more saline Aegean waters were observed, both as lenses and as a distinct layer, outside the Arc region of Kriti, at depths of 700-1 100 m, between the LIW and EMDW of Adriatic origin (MALANOTTE-RIZZOLI *et al.*, 1997).

In the past few years and more specifically starting from 1987, it has been recognised that the thermohaline circulation and the deep water hydrological properties of the eastern Mediterranean Sea have undergone significant changes (Figure III.19b). In contrast to the slow long term drifts in temperature and salinity that have been observed in the entire Mediterranean for several decades, the above changes represented a qualitative jump. This abrupt event was called the ‘**E**astern **M**editerranean **T**ransient’ (**EMT**) and was attributed to the shift of the ‘driving engine’ for the deep water formation from the Adriatic to the Aegean Sea (Figure III.20).

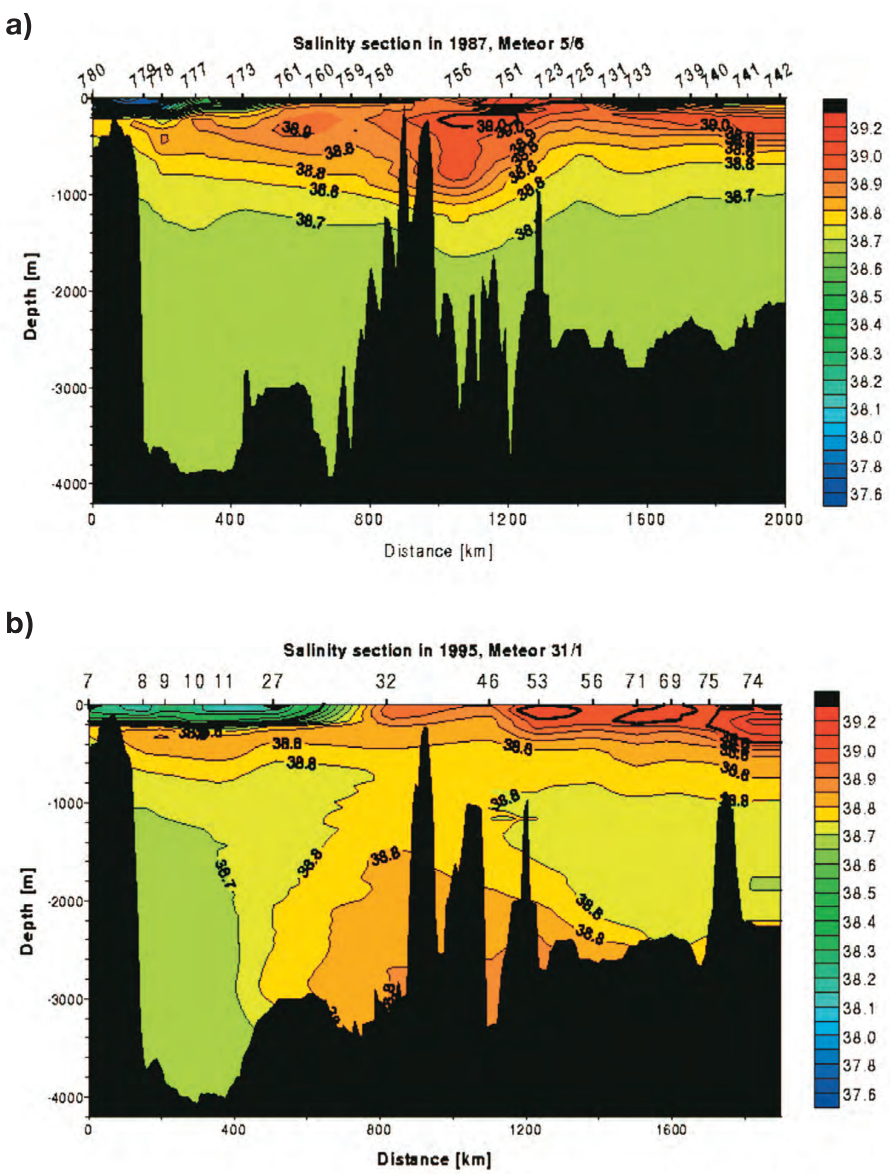


Source: *LASCARATOS et al., 1999.*

Figure III.18:
Intermediate and Deep water formation sites and Thermohaline circulation in the Mediterranean.

The latter became a new, more effective source than the old one, since it produced not only denser water, namely the Cretan Deep Water, but also higher volumes. ROETHER *et al.* (1996) estimated that the total volume of the Aegean water entering the eastern Mediterranean during the period 1988-1995 is 2.3X10^{14} m^3, which corresponds to a mean transport of 1 Sv for 7 years, although seasonal and interannual modulations exist. A combined effect of a series of episodes of anomalous atmospheric forcing acting on a favourable oceanic background seems to be the cause and origin of the EMT.

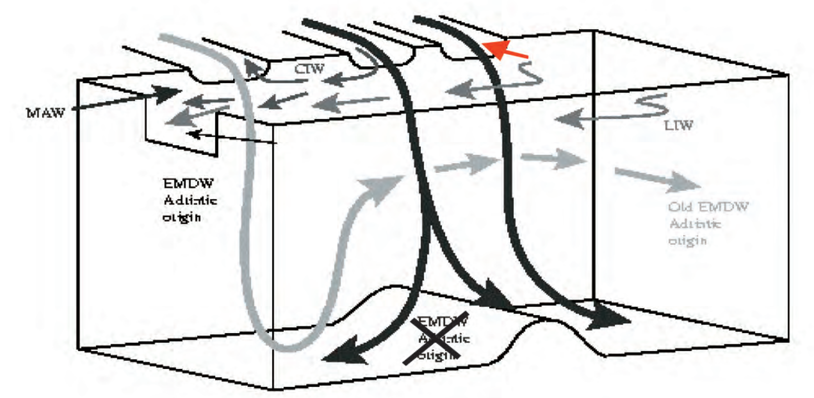
The evolution of the intense dense water formation in the south Aegean is shown in Figure III.21. A continuous increase of density inside the basin started in 1987. In 1992 the basin was already filled up to the surface layer with young dense water. After 1992-93, due to the continuous diminishing CDW formation rates and overflow, the CDW layer has been deflated and is now observed below 500-600 m. The density of the CDW reached its maximum value (29.4 kg/m^3) in 1994-95, while the maximum production rate (3 Sv) was reached in 1991-92. From 1988 to 1995, a massive outflow of CDW occurred through the Straits of the Arc of Kriti towards the Ionian and Levantine basins. The CDW



Source: *ROETHER et al., 1996.*

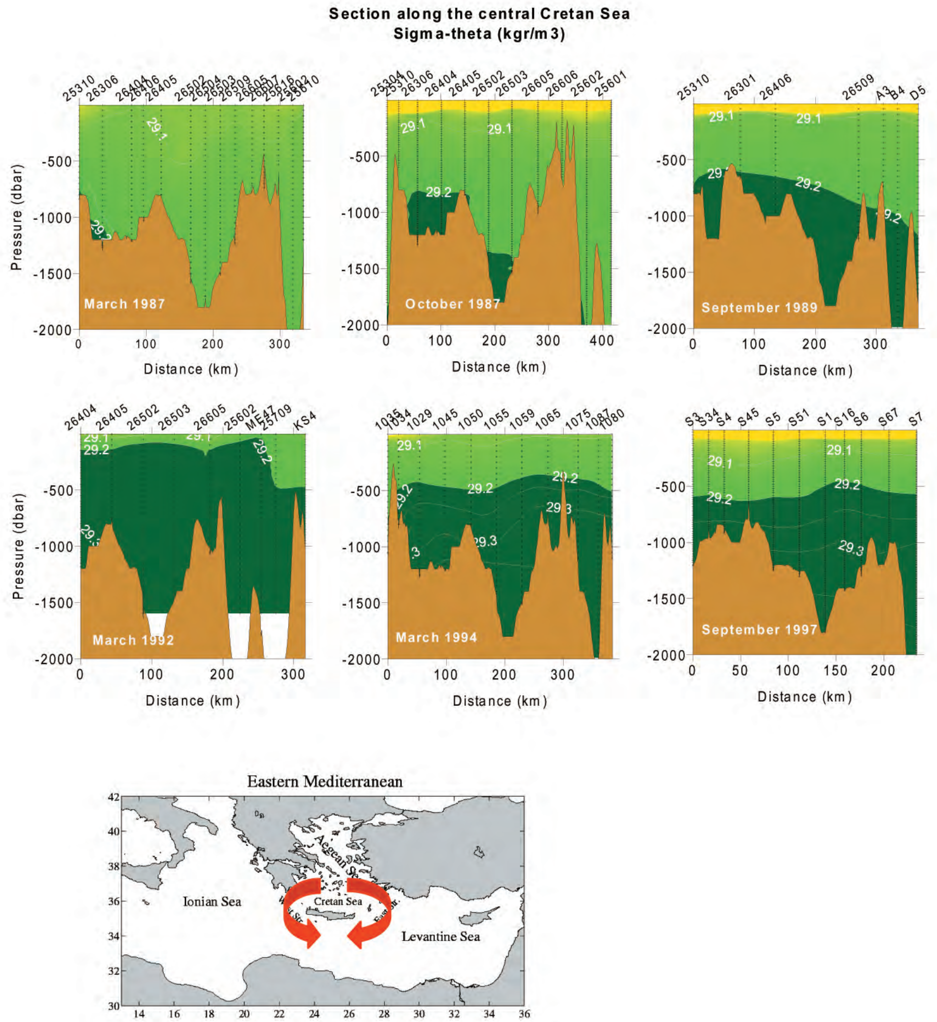
Figure III.19:
Vertical salinity distribution along a west-east section in the eastern Mediterranean during (a) 1987 and (b) 1995.

Figure III.20:
The thermohaline circulation of the eastern Mediterranean, 1995.



Source: *ROBINSON et al., 2001.*

Figure III.21:
West-East sigma-theta (density) cross sections in the Cretan Sea from 1987 to 1997. Values higher than 29.2 kg/m^3 are shaded.



Source: *modified from THEOCHARIS et al., 1999.*

being of particularly high density affected primarily the near-bottom layers, uplifting the older deep waters of Adriatic origin (Figure III.19b). ROETHER *et al.* (1996) estimated that in 1995 20% of the deep waters of the eastern Mediterranean were already replaced by this new warmer and more saline CDW.

The changes in the CDW production rate are well correlated with the variability in the heat and freshwater forcing including the extreme meteorological events such as the long dry period (1987-1992) in the eastern Mediterranean and especially over the Aegean, and the extremely cold winters of 1987, 1992 and 1993. The time history of both the deep water hydrological characteristics in the south Aegean and the weather conditions outlines two distinct periods of the EMT evolution and indicates that two mainly different forcing factors have acted. The first period 1987-1992 was mainly salinity driven; the salinity inside the south Aegean increased by 0.15 psu, due to a persistent period of reduced rainfall and intensified evaporation caused by stronger northerlies. Moreover, significant changes in the circulation patterns in the eastern Mediterranean have affected the traditional water-mass pathways (AW and LIW) and thus the involved processes resulting in an increase of salinity in the Levantine basin and a significantly enhanced net upper layer salt transport into the Aegean during the period 1987-94. All the above factors have superimposed on the already existing slow long term increasing trend in salinity (BETHOUX *et al.*, 1998) due to the damming of major eastern Mediterranean and Black Sea rivers. Finally, the second period 1992-1994 is characterised by a remarkable cooling of the CDW in the order of 0.35˚ C, directly related to the extremely cold winters of 1992 and 1993, when the winter mean air temperature was 2˚ C lower than average winter values (THEOCHARIS *et al.*, 1999).

Since 1995, the event started to decay dramatically confirming its transitional character. However, the Aegean Sea still functioned as the main source of deep waters for the eastern Mediterranean Sea although with modified characteristics. The outflowing CDW is no longer dense enough to reach the bottom of the adjacent basins, but ventilates layers between 1 500 and 2 500 m (THEOCHARIS *et al.*, 2002a). Only the deep eastern Cretan Arc Straits are still active in the discharge of CDW, while at the western end the density was reduced significantly. At the same time, the spreading of the high density CDW that had been accumulated in the passage of Kriti in the first phase of the EMT has progressed further, both eastwards and westwards. Thus, a considerable deposition of salt has been observed in the deep and bottom layers with a simultaneous decrease of salinity in shallower waters.

It is worth noting that the abrupt changes in the hydrology and dynamics of the eastern Mediterranean have greatly affected the distribution of other basic environmental parameters, such as oxygen and nutrients, in the water column of the entire basin, thus modifying the conditions in the ecosystem (Chapter IV).

Finally, important issues can be addressed concerning the future evolution of the EMT, its probable influence on the western basin and the adjacent ocean and its impact on the ecosystem. Is the system going to relax and when? Is the eastern Mediterranean going to return to its previous functioning with a single source of deep water production in the Adriatic or evolve to a new quasi-steady state? These are only few among numerous questions that require answers through systematic monitoring and modelling studies.

SEA WATER VARIABILITY IN THE EASTERN MEDITERRANEAN SEA

The upper and intermediate layers of the eastern Mediterranean Sea have been undergoing a decrease in temperature and increase in salinity, during the second half of the last century (THEOCHARIS *et al.*, 2002b; PAINTER & TSIMPLIS, 2003) and consequently an important increase in density. In the Levantine and Cretan seas the changes in density at the level of the AW (identified by a salinity minimum) exceed the 1 kg/m^3, while in the Ionian data are noisier, although similar trends are present too. At the core of the LIW (identified by a salinity maximum), a general increase in density is observed in all sub-basins of the eastern Mediterranean Sea. This change is mainly caused by a decreasing trend in temperature and secondarily by increasing trends in salinity (more pronounced in the Cretan and Ionian seas). An important factor in the changes at intermediate levels is the significant increase in the salt content of the Cretan Sea which, in turn affects large areas of the eastern Mediterranean through the so-called **C**retan **I**ntermediate **W**ater (**CIW**). The origin of these changes is most likely related to the variability of the atmospheric conditions in the region and to changes in water budget caused by anthropogenic processes, such as the damming of the River Nile (SKLIRIS & LASCARATOS, 2004).

Although a strong variability of the sea water properties can be detected in all levels of the eastern Mediterranean Sea, changes in the atmospheric conditions and the air-sea interaction are best reflected in the deeper layers of the sea, which are in some way the 'climatic memory' of the ocean. Indeed, deep water-masses bear the memory of the actual conditions that prevailed during their formation and keep them 'locked in' for many years. Temperature, salinity and density time series over the second half of the last century for the Levantine, Ionian and Cretan seas were constructed using the MEDATLAS data base, which combines pre-existing databases such as the MODB data set, with more recent data. In this study, focusing mainly on the deep waters, the depth of 2 000 m is selected as a reference level for deep water monitoring in the Levantine and Ionian basins while the depth of 1 000 m for the Cretan Sea, which is not far from its mean depth and sill depths. The choice of depths reflects also the availability of data. Figure III.22 presents the time series for the three basins.

In the deep layers in all regions we can observe positive trends for all three parameters. But the most important feature is the saw-tooth jagged form of the time series revealing two major events, one centred in the mid-1970s and the second one approximately 20 years later. The most recent is the well known Eastern Mediterranean Transient. The second one is detected in the 1970s and concerns a considerable increase of salinity and density. Such behaviour indicates that the thermohaline circulation in the region is very sensitive to changes in the external forcing. Because of its small dimensions and the complicated topography which divides the basin into several sub-basins, the eastern Mediterranean Sea's response to atmospheric forcing is very rapid and on much smaller time scales compared to the global ocean.

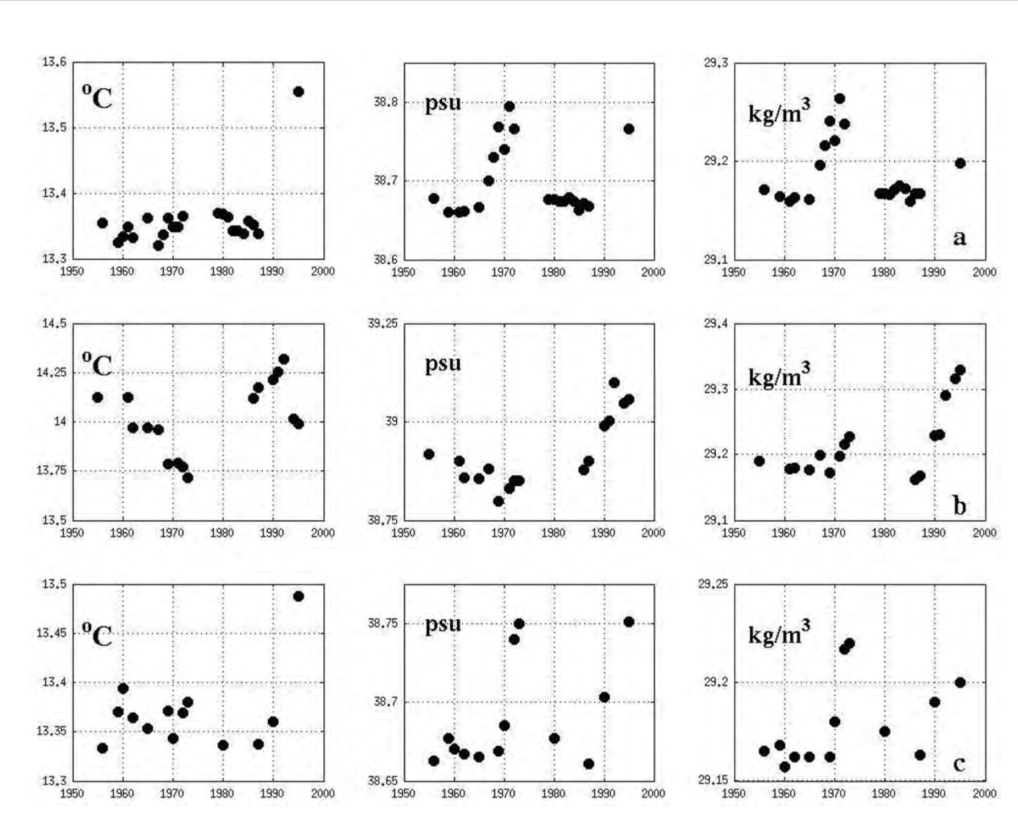


Figure III.22: *Potential temperature, salinity and sigma-theta in (a) the Levantine Basin (2 000 m), (b) the Cretan Sea (1 000 m), and (c) the Ionian Sea (2 000 m).*

VARIABILITY OF THE AIR-SEA INTERACTION IN THE EASTERN MEDITERRANEAN

Figures III.18 and III.20 present what is known as the 'climatology' of the Mediterranean Sea or the 'mean state' under the average atmospheric conditions of the present climatic status. However, the atmospheric conditions vary significantly in various time-scales, ranging from a few years or decades up to thousands of years. These changes leave their 'imprints' on the Mediterranean Sea, which responds energetically, modifying various aspects of the circulation and water-mass formation processes as well as the water-mass characteristics.

Although the eastern Mediterranean Sea is subject to lateral forcing (mainly through the inflowing AW) and anthropogenic influence (e.g. changes in the water budget through river damming) its interaction with the atmosphere is the dominant mechanism responsible for changes in the circulation and water-mass structure of the sea. The evolution of atmospheric parameters and the sea surface temperature over the eastern Mediterranean Sea, derived from the Comprehensive Atmosphere-Ocean Data Set (COADS – Da SILVA *et al.*, 1994), is used here to highlight basic patterns of air-sea interaction in the region. The dataset comprises monthly mean values with one degree spatial resolution and covers approximately the second half of the last century (1945-1993). Strong seasonal signals and Quasi-Biannual Oscillation are evident in all parameters. This high frequency variability is filtered, in order to focus on longer term variability.

The low frequency time series of all parameters show significant variability, on various time-scales, ranging from a few years to two decades. In some cases an underlying continuous trend is also evident. In Figure III.23 the total heat flux across the air-sea interface, the freshwater flux (evaporation minus precipitation) and the wind speed are presented and discussed briefly in the following.

The total heat flux (Q_{tot}) undergoes an important interannual variability, of the order of 15 W m^{-2}. Very pronounced minimum values (maximum

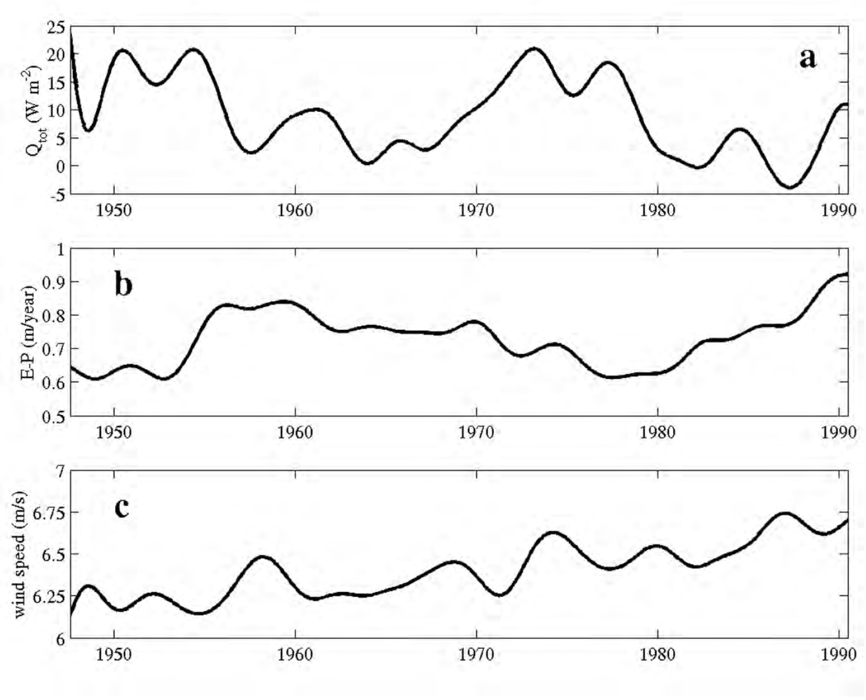


Figure III.23:
Total heat flux (a), fresh water flux (b) and wind speed (c) low frequency time series over the Eastern Mediterranean.

heat loss) are observed during the mid-1960s and late 1980s, whereas the most outstanding maximum is observed during the mid-1950s and mid-1970s. Most of the variability observed in the heat budget is due to similar changes in the latent heat loss (associated with the evaporative freshwater loss from the sea surface). An important variability is also evident in the freshwater flux (E-P). The most pronounced feature is the sharp increasing trend in freshwater loss from the surface of the sea from the late 1970s to the early 1990s, of the order of about 50%. This trend is mostly attributed to a drastic decrease in the precipitation, which during the same period is reduced from 0.6 m/year to 0.3 m/year. Finally, the magnitude of the wind speed shows a continuous increase during the 50 years' period in the eastern Mediterranean Sea. This trend is accompanied by a shift in the wind direction by about 20 degrees, resulting in a stronger northerly component. It is very interesting to notice, that the variability in the wind pattern results in changes of the wind stress curl. In the Ionian Sea it shifts periodically (with a periodicity of 10-15 years) from positive to negative values, a factor that can affect the circulation in the region and the exchange between the western and eastern Mediterranean Sea.

The variability observed in the air-sea fluxes time series is also evident in the sea surface temperature evolution during the same period (Figure III.24). An important variability, that can almost reach 1˚ C, is observed, with a very pronounced maximum during the early 1960s and a very pronounced minimum in the mid-1970s. If we compare this time series with the total heat flux (Figure III.23) it is obvious that there are periods where the trends of the two variables have the same sign and periods with changes in an opposite direction. While the former is easily explained as the direct influence of the atmospheric condition on the sea surface, the latter must involve other processes, such as the oceanic advection.

SEA LEVEL VARIABILITY AROUND THE HELLENIC COASTS

Sea level variations result from changes in the oceanic circulation, water-mass characteristics and atmospheric forcing as well as global changes in the volume of oceanic water. Thus, they can be considered as resulting from the integrated impact of oceanographic forcing on the coast.

Every coastal community is, in principle, vulnerable to changes in sea level. Existing coastal development and infrastructure has been designed on the basis of an assumption of stationary sea

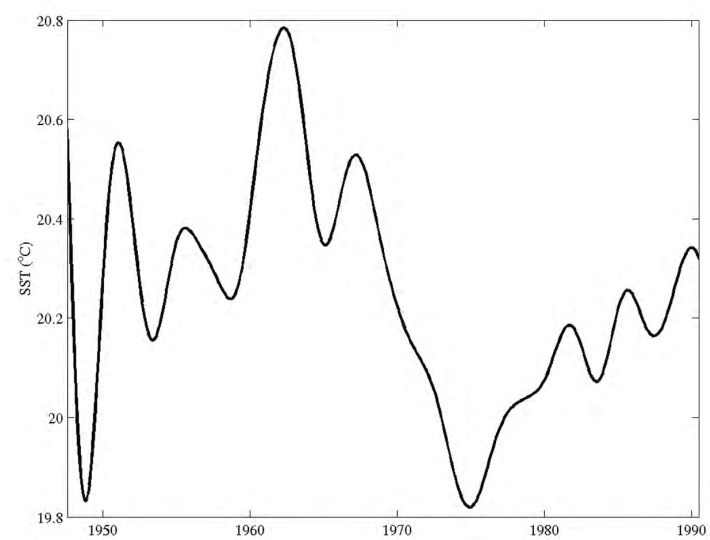


Figure III.24:
Sea surface temperature over the Eastern Mediterranean Sea.

level with an assumed steady distribution of return periods for extreme sea levels. Nevertheless, the sea level is rising globally by about 10-20 cm per century and is expected to rise faster in the future (CHURCH *et al.*, 2001). In addition, there is a (less certain) possibility of changes in the observed extremes. Thus, accurate sea level measurements have become of paramount importance for national and global studies.

Sea level measurements are presently made either by tide-gauge networks or by the use of radars on satellites, termed as altimetry. Tidal predictions, flood warnings geodetic studies relevant to datum determination for hydrographic and land applications, extreme sea levels studies for engineering applications and long term studies for climatic scale changes to mean sea level are mainly reliant on the availability of tide-gauge data. Satellite altimetry is best suited for data assimilation to models for operational monitoring of water quality marine ecosystems and oceanographic circulation although it can provide information on other aspects too.

Tide-gauges measure sea level relative to the land, thus land movements are included in the record and have to be separated by other techniques. The major land movements are either on scales of centuries and low in magnitude or sudden movements linked with tectonic actions and earthquakes (ZERBINI *et al.*, 1996). With due care it is possible to identify the latter in the tide-gauge records while the long term movements must be measured or estimated independently if they are to be removed.

SEA LEVEL MEASUREMENTS

More than twenty tide-gauges have been in operation in Hellas during the last decades. The **H**ellenic **N**avy **H**ydrographic **S**ervice (**HNHS**) is the national authority operating those tide gauges (TSIMPLIS & SPENCER, 1997). The author, during his national service at the HNHS, found notes referring to the existence of a tide-gauge in Peiraias during 1891-1893. Unfortunately, no data relating to this period were found. No satellites are operated nationally but Hellas participates in the European Space Agency missions and in any case, all data collected by altimetric satellites are presently freely available for all applications.

The operation of the tide-gauge network of the HNHS had, as a major objective, the determination of the bathymetry for charts. Thus, the required accuracy was for many years of the order of tens of centimetres which is rather inaccurate for scientific purposes (TSIMPLIS & BLACKMAN, 1997). Moreover, although the operation by a military organisation ensured the continuity of the network as funding was provided under the general budget for the Navy, the treatment of the obtained data as confidential for many years meant that the deficiencies of the measurement network took longer than they should have to become apparent. This has changed recently and the HNHS is working in partnership with other European sea level authorities and with leading scientists for the development of the **E**uropean **S**ea **L**evel **S**ervice (**ESEAS**) (see http://www.eseas.org/) which will ensure the provision of quality controlled, hourly, sea level data in near real time conditions. Nevertheless, not all the Hellenic tide gauges will be included in ESEAS at this first stage of development.

LONG TERM MEAN SEA LEVEL CHANGES IN THE AEGEAN AND THE IONIAN SEAS

From the 20 available mean monthly sea level records provided by the HNHS to the Permanent Service for Mean Sea Level database, 14 do not include obvious problems. Nevertheless, even these relatively better stations do not show consistency with each other (Figure III.25a). Of course, each of them is contaminated by land movements which differ between locations but these are unlikely to be able to produce sudden and reversible changes of 5 cm or more within a few years. Thus, a problem with the quality of the data becomes apparent. Averaging those stations produces the blue curve shown in Figure III.25b which is consistent with the longest and best quality tide-gauge record in the eastern Mediterranean, that of Trieste. This is not surprising as several studies have shown coherency of the Mediterranean Sea level at various time scales (see for example, LASCARATOS & GACIC, 1990; ZERBINI *et al.*, 1996; TSIMPLIS & JOSEY, 2001). The long term picture for the eastern Mediterranean is one of increase of sea level of around 1.5-2 mm/yr from the beginning of the 20th century until about the 1960s. Between the 1960s and the early 1990s sea level was reducing in the Mediterranean by about 0.1- 0.5 cm/yr (TSIMPLIS & BAKER, 2000). This was followed by an increase of about 8 cm between 1993 and the present (CAZENAVE *et al.*, 2001; TSIMPLIS & RIXEN, 2002).

There have been very few studies of extreme sea levels and their changes in time in the eastern Mediterranean (TSIMPLIS & BLACKMAN, 1997). Reduction of wind speed in the Adriatic Sea has led to reduction in the extremes (PIRAZZOLI & TOMAZIN, 1999). Nevertheless, although the mean sea level variability is coherent within the Mediterranean it has not been shown that similar coherency exists for the extremes of the sea level distribution. Thus, such a generalisation cannot be made particularly because the wind systems are distinctively different. Nevertheless, the reduction of sea level for many decades and the sudden recent increases are likely to dominate any changes in extreme values.

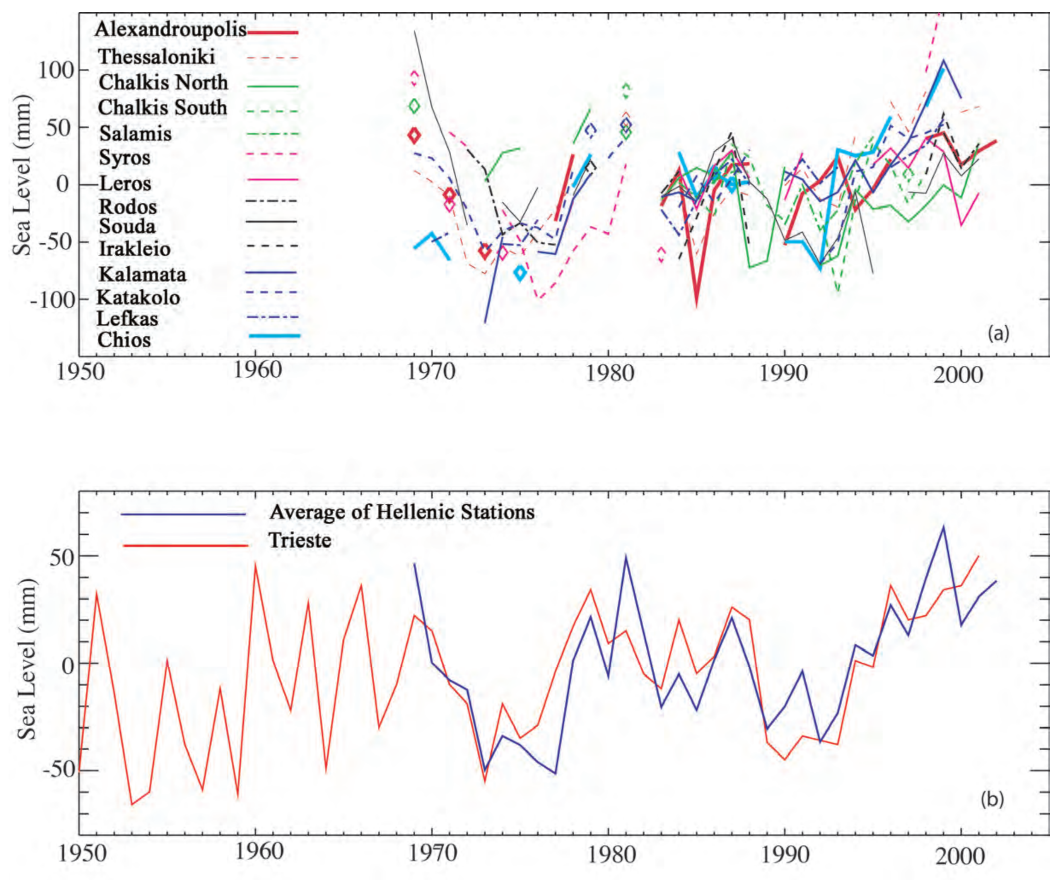


Figure III.25:
(a) Mean annual sea level from thirteen tide gauges in the Hellenic Seas.
(b) The average of the time series shown in (a) together with the mean sea level in Trieste, the longest good quality station in the Eastern Mediterranean.

III. GAPS IN KNOWLEDGE - FUTURE PERSPECTIVES

As more data become available and numerical modelling techniques are developed, our understanding about the hydrology, the general circulation and the water mass formation in the eastern Mediterranean and in the Hellenic marine environment is improved. At the same time, new questions arise concerning the long-term variability of the eastern Mediterranean Sea and its impact on the ecosystem and human activities. The variability in water-mass characteristics and the redistribution of water masses in the eastern Mediterranean may have a strong impact on the delicate ecosystem of this region. Accordingly, risks of deep anoxia and enhanced stresses on the coastal areas are issues of primary importance.

In our future efforts, we need to further understand the dominant patterns of variability at the various time-scales in the sub-basins of the eastern Mediterranean Sea, including the Hellenic waters, and their relation to the corresponding global and regional weather patterns. Emphasis should be made so that the future investigations on the various patterns of variability have a multidisciplinary approach.

Given the complexity of the atmosphere-ocean system and the inherent time-scales, there is a central need for long-term consistent data to support climate and environmental change investigations. Research observational data sets that span significant temporal and spatial scales are needed so that methods and models for attributing, understanding and projecting to the future climate change in the region can be validated and refined.

Similarly for the coastal areas, a basic drawback with respect to the hydrology and the dynamics is lack of knowledge of the hydrodynamical variability both on synoptic scales (a few days to a few weeks) and in the long term (years to decades) in view of the existing trends. In the coastal areas of the Saronikos Gulf and the Thermaikos Gulf continued monitoring programmes have focused on obtaining and maintaining long time series of several environmental parameters for almost the last ~10 years. The investigation of long-term trends in hydrologic characteristics requires at least a 20-year record of uninterrupted good quality data.

With respect to the synoptic variability on coastal flow structures, the realisation and scientific analysis of circulation pictures that would combine the direct current observations of the flow structures with the associated behaviour in terms of the synoptic variability remains a future target for most of the Hellenic coastal marine areas.

In the coastal water-level measurements, the rapid improvement of the accuracy of the tide-gauge network and the monitoring of the benchmarks must be a clear priority and the Hellenic Navy Hydrographic Service must be supported by the scientific community and the government in order to improve the network and exploit the data collected in an efficient manner. For research purposes all the sea level data available at the HNHS database must be made freely available to all scientists. Revision of the existing measurements by experts together with re-digitisation of old charts to ensure datum continuity will also significantly improve our understanding. Land motion measurements by continuous GPS (CGPS) at the tide-gauge sites is developing into a norm in the sea level community and is considered as promising for the separation of sea level and land movements. Studies on changing of the extremes in sea level are also needed. Most importantly, understanding of the forcing of sea level variability through empirical and modelling studies must be achieved in order to apply the global forecasts of climate change to the eastern Mediterranean in which regional variability and local phenomena dominate the climate signals at least during the past four decades.

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CHAPTER IV
CHEMISTRY

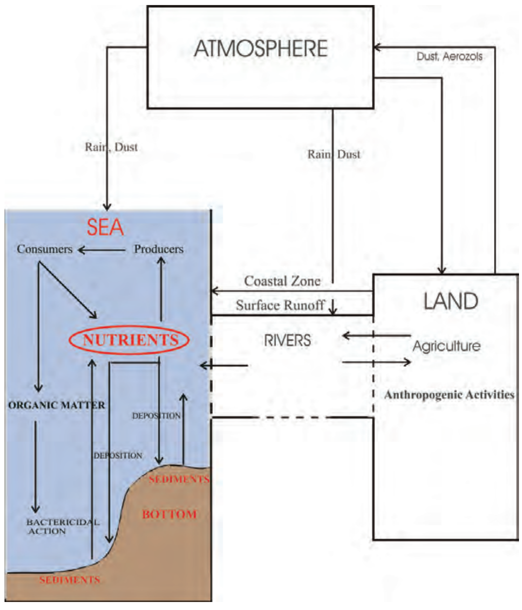
IV.1. NUTRIENTS AND DISSOLVED OXYGEN IN HELLENIC COASTAL WATERS

Nutrients are used for growth by marine phytoplankton until they become limited and further growth is prohibited. The most important micronutrients are nitrogen and phosphorus. Some organisms (diatoms) have siliceous frustules and require silica. In sea water the principal inorganic forms of nitrogen are nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+). According to Redfield, the relationship between Si, N and P in sea water based on the average composition of plankton is 16:16:1 for Si:N:P.

The most important pathways of nutrients' input into coastal waters are **rivers discharges, run-off from agricultural sites, pollution** (e.g. sewage, industrial effluents) and over the whole area, **the atmosphere** (Figure IV.1).

It is obvious that nutrient concentrations are the principal factors affecting the marine ecosystem, as the movement of nutrients from land and the atmosphere into marine waters is an important influence on the chemical and biological conditions of the waters. Nutrients are commonly found in soils, plants and animals and it is, therefore, important to differentiate between the normal geochemical fluxes of nutrients into the sea water (e.g. through rivers) and fluxes augmented by human activities (e.g. industrial-municipal outfalls).

The seasonal variations in nutrients occur in the euphotic zone as a result of biological activity, whereas the spatial variations occur as a result of the physical processes prevailing in the coastal areas, the various Land Based Sources (LBS), the riverine inputs, etc. High nitrate and phosphate levels can change the Redfield ratio and often stimulate algal blooms, some of which are toxic or harmful in coastal marine waters. High nutrient concentrations usually lead to high mass production of algae which when decomposing may result in oxygen depletion.



Source: *RILEY & CHESTER, 1971. Modified by A. PAVLIDOU.*

Figure IV. 1:
Bio-geochemical processes in coastal zones.

The assessment of nutrient levels in various Hellenic coastal areas influenced by anthropogenic activities, sewage outfalls, riverine outflows, etc. presented below, is based on available data collected during research programmes studying the environmental quality of the Hellenic coastal zone between 1987 and 2002.

Water samples are usually collected at standard or selected depths, using NISKIN bottles to measure nutrients (N-NO_2, N-NO_3, P-PO_4, Si-SiO_4), stored in 100 ml polyethylene bottles and kept continuously frozen (-20 ˚C), until their analysis in the laboratory by a nutrient auto-analyser (Bran & Luebbe Autoanalyzer II) (Figure IV. 2).

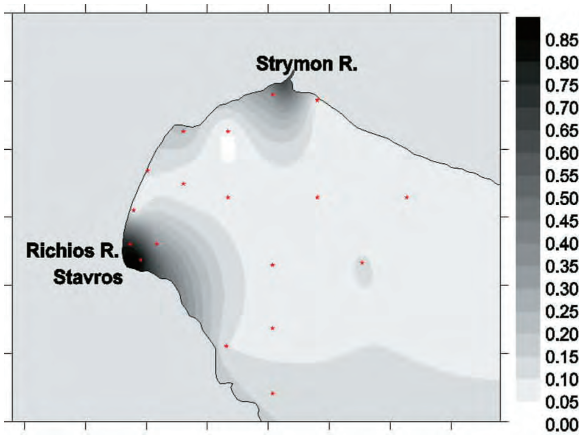
Inputs of nutrients via rivers

Rivers, which have an important local bearing as regards coastal fertilisation affecting coastal marine ecosystems, continue to be a matter of concern throughout the developing world. Typical examples in Hellas are the Strymonikos, Argolikos and Amvrakikos gulfs (PAVLIDOU *et al.*, 2002a; ARCHODITSIS *et al.*, 2001; FRILIGOS *et al.*, 1997). Many factors (e.g. agriculture in the catchment area of the rivers, and/or the manure or the fertiliser applications) contribute to the complexity of the processes affecting nutrient concentrations in such regions.

The principal environmental load of nutrients flowing into the *Strymonikos Gulf* is provided by agricultural activities. High nutrient concentrations are recorded very close to the mouth of the rivers, showing a decreasing trend with distance. The nutrient distribution follows the salinity contours and shows clearly that the influence of the riverine waters is restricted close to the mouth of the river (Figure IV.3). For example, concentration of nitrate varied from 44.0 μg-at/L near the mouth of the

Photo: *A. CATSIKI*

Figure IV. 2:
Analyses of nutrients in sea water HCMR, Biogeochemical laboratory.



Source: *PAVLIDOU & GEORGOPOULOS, 2001.*

Figure IV. 3: *Surface distribution of phosphate in the Strymonikos Gulf in December 1997.*

Strymon River, to <1.00 μg-at/L, southwest of it. The seasonal variability in the nutrient loads entering the coastal areas is correlated to the seasonal variation in runoff. In general, the plots between nutrient concentration and salinity show quite a linear relationship, indicating that the dilution process is the predominant factor that controls the distribution of nutrients (Figure IV.4).

Input of nutrients via domestic and industrial effluents

In addition to the input of nutrients through the rivers, nutrients are supplied to coastal waters from sewage treatment plants and/or from certain types of industries (e.g. fertiliser industries). Representative Hellenic coastal areas, which receive nutrient loads from human activities (sewage outfalls, industrial effluents) are the Saronikos Gulf, Thessaloniki Bay, Elefsis Bay and Kavala Bay (PAVLIDOU *et al.*, 2004; PAVLIDOU & PSYLLIDOU-GIOURANOVITS, 2004; SYLAIOS *et al.*, 2000).

Since 1994 the sewage generated by the city of Athens (population ~4 000 000) has been primarily treated in the Psittalia Treatment Plant, diverting the effluents into the Saronikos Gulf, at a depth of 63 m. Nutrient levels and their spatial distribution in the inner Saronikos Gulf are presented in Figures IV.5 and IV.6, showing a decreasing trend with distance from the sewage treatment plant towards the outer Saronikos Gulf, indicating that water circulation and dilution processes are the predominant factors controlling nutrient concentrations in the Saronikos Gulf. Significant variation of nutrient concentrations with time is observed, showing higher concentrations mainly in cold sampling periods, probably associated with the discharges of the primary treated sewage and/or to the higher municipal load during the cold period, as well as to the internal recycling processes of nitrogen, phosphorus and silicon.

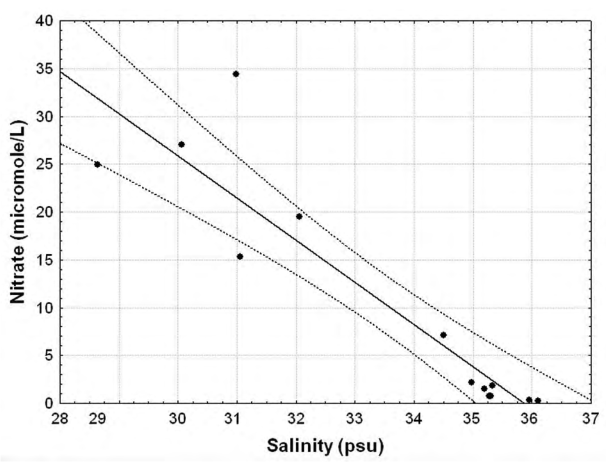
Temporal data for the 1987 to 2002 period, have revealed a decreasing trend of the N:P ratio near the Psittalia WWTP, despite the increasing trends of phosphate and nitrate concentrations. This implies that the increase of phosphate was significantly higher than that of nitrate.

Figure IV.7 shows a non-statistically significant decreasing trend ($p>0.05$) in phosphate concentrations in Thessaloniki Bay for the period 1995-2002. It is also noteworthy, that phosphate concentrations followed no trend during the period 1998-2002. This is probably due to the decrease of the untreated load of effluents from the city of Thessaloniki.

Nutrient concentrations in the Kavala Gulf are related to the intense industrial activities (a phosphoric fertiliser plant, wastewater treatment works, oil refineries, sea mariculture facilities and a commercial harbour). For example, the Chemical Industry of Phosphoric Fertiliser Plant (PFP) enriches the coastal zone of Kavala with phosphate.

Inputs of nutrients via a combination of human activities

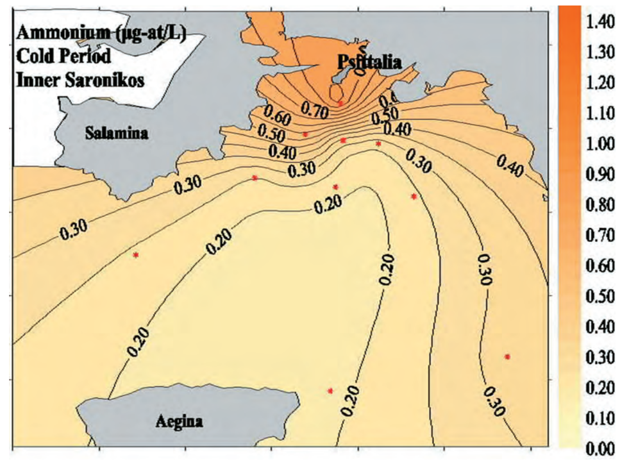
Some of the Hellenic coastal areas receive nutrients from both agricultural activities and domestic/industrial inputs. Typical examples are:



Source: *PAVLIDOU et al., 2002a.*

Figure IV. 4:
Nitrate-salinity correlation at the surface of the Strymonikos Gulf in December 1997.

Figure IV.5:
Horizontal Distribution of Ammonium during the cold period in the inner Saronikos Gulf: Mean integrated values for the period 2000-2002.



Source: *NCMR, 2002.*

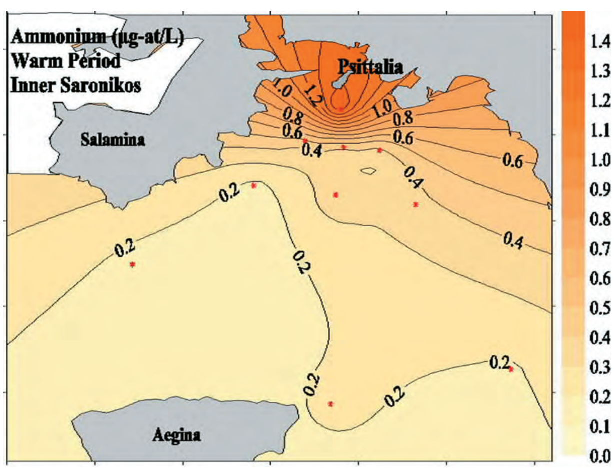
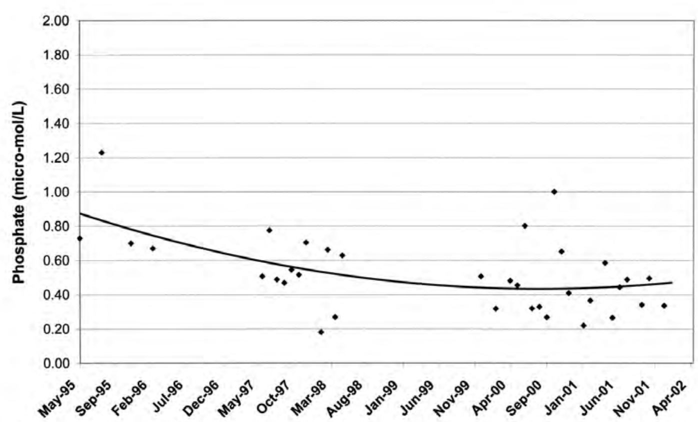


Figure IV.6:
Horizontal Distribution of Ammonium during the warm period in the inner Saronikos Gulf: Mean integrated values for the period 2000-2002.

Figure IV.7:
Temporal trend of phosphate in Thessaloniki Bay.



Source: *NCMR 1996a & HCMR, 2003a.*

the Pagasitikos Gulf, the Thermaikos Gulf, the Gulf of Gera and Kalloni Bay (TSIRTSIS *et al.*, 2002; KOLLIOU, 2000).

The coastal area of the inner Thermaikos Gulf is affected by three major rivers (Axios, Loudias, Aliakmon) along the western coast and also receives domestic, agricultural and industrial effluents, not only through the rivers, but also from the sewage discharges from the city of Thessaloniki (~one million inhabitants), located at its northern part (Thessaloniki Bay).

The seasonal variability of nutrient concentrations in the study area is related to the Thessaloniki municipal sewage outfall, the agriculture and aquaculture activities in the area, the existence of the thermocline during the warm period, the enhanced anthropogenic activities and the various point sources, which enrich the study area in pollutants, as well as the fluctuation of the flow rate of the main rivers affecting the study area.

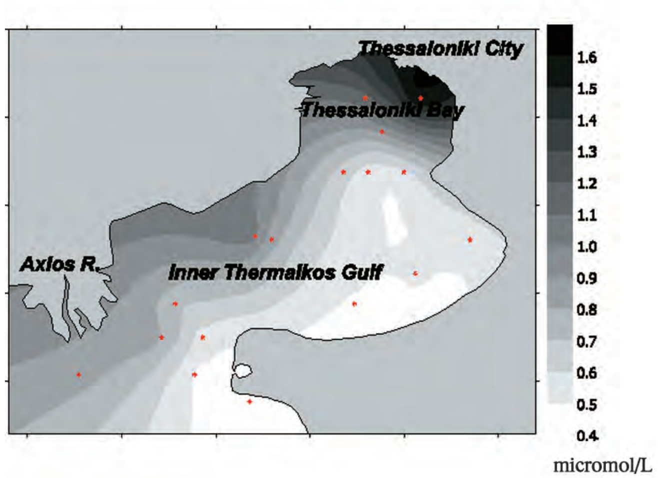
In general, significant spatial variability was observed, with high values of nutrients near the mouth of the rivers and the aquacultures near the west coastline of the gulf (Figure IV.8).

A time-series (1995-2002) analysis of nutrients in the inner Thermaikos Gulf (including Thessaloniki Bay), has revealed that DIN showed a decrease which was statistically non-significant, whereas nitrate showed a statistically non-significant increase and phosphate did not seem to follow any trend. On the contrary, ammonium showed a statistically significant ($p<0.05$) decrease. This has resulted in the decrease of the N:P ratio in the area which may lead to algae blooms, some of which may be toxic (PAGOU *et al.*, 2003).

The Gulf of Geras (Lesvos Island) is another representative example of coastal areas with agricultural and sewage nutrient load. The gulf is connected with the open Aegean Sea through a channel (channel width: 200-800 m, length: 6.5 km and depth 10–30 m). The most important discharges into the gulf are untreated domestic wastewater and effluents from the local industrial activities, especially olive oil processing by-products. The flux of nutrients from non-point sources (agricultural run-off) is considerable, especially during the winter period, when the contribution to the total inorganic nitrogen stock (the limiting nutrient in the area) varies between 40 to 60%. The input of nutrients and organic matter from the surrounding water-shed and the low renewal rate may lead to eutrophication crisis during the year.

Inputs from tourist activities

The *Petalioi Gulf* is an example of a rather unpolluted area, which receives domestic and agricultural inputs from the sewage discharges of the small towns, mostly summer resorts, located along the eastern coast of Attiki, as well as from the Asopos River dicharges. Despite that, the area has the character of an open-sea area with very low nutrient concentrations. It is noteworthy, that the relatively higher phosphate and nitrate values measured in the warm period (summer) near the eastern coast of Attiki are related to the domestic effluents of the summer resorts (Porto Rafti, Rafina,



Source: *HCMR, 2003a.*

Figure IV.8:
Surface Distribution of Phosphate during April 2000 in the Thermaikos Gulf.

Loutsa, etc.) (Figure IV.9) (PAVLIDOU & PSYLLIDOU-GIOURANOVITS, 1997).

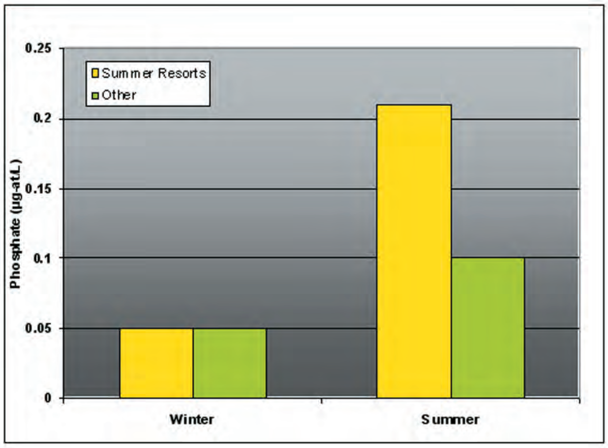
Undisturbed to slightly disturbed areas

Regardless of the pressure by LBS, in some Hellenic coastal areas, the nutrient concentrations are very low, indicative of oligotrophic marine environments. In these cases, the water circulation and dilution processes are the predominant factors controlling the nutrient distribution. Coastal areas with an oligotrophic character are the Sea of Kerkyra, the coastline of the Ionian Sea (Kalamitsi - Preveza), the Lakonikos Gulf, the south Evvoikos Gulf and Rodos Island (KARYDIS *et al*., 1995).

For example, in Rodos Island, the intense circulation and mixing of the waters, associated with the small extension of the continental shelf and the abrupt increase in depth, continuously expose the island's coasts to the open seas of the Aegean Sea and Levantine, with minimal to zero influence from LBS. Therefore, the coastal zone of Rodos Island has the character of an open-sea area with very low nutrient concentrations (Figure IV.10).

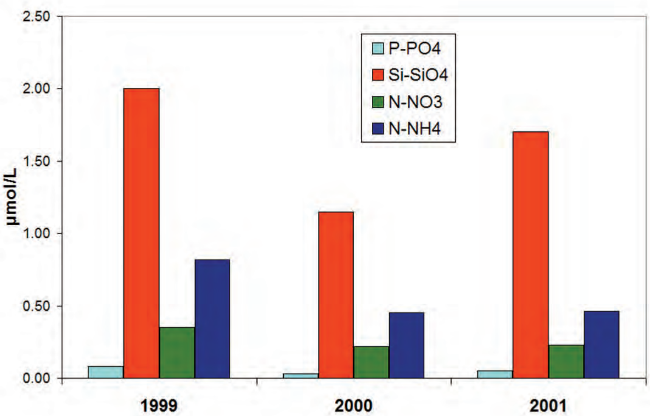
The mean integrated nutrient concentrations in the winter and summer periods along the Hellenic coastal areas are presented in Table IV.1. According to these values and the water quality indices for the Hellenic coastal zone (Table IV.2), the water quality of the studied coastal areas can be divided into four main categories: unpolluted areas, rather unpolluted areas (low nutrient concentration), intermediate polluted areas (moderate nutrient concentration) and polluted areas (high nutrient concentration). Following this classification, the water quality of Hellenic coastal waters according to nutrient concentrations is depicted in Figure IV.11 (a-f).

Figure IV.9:
Mean integrated values of phosphate in the Petalioi Gulf, during winter and summer.



Source: *NCMR, 1997.*

Figure IV.10:
Annual mean nutrient concentrations of nutrients in Rodos Island.

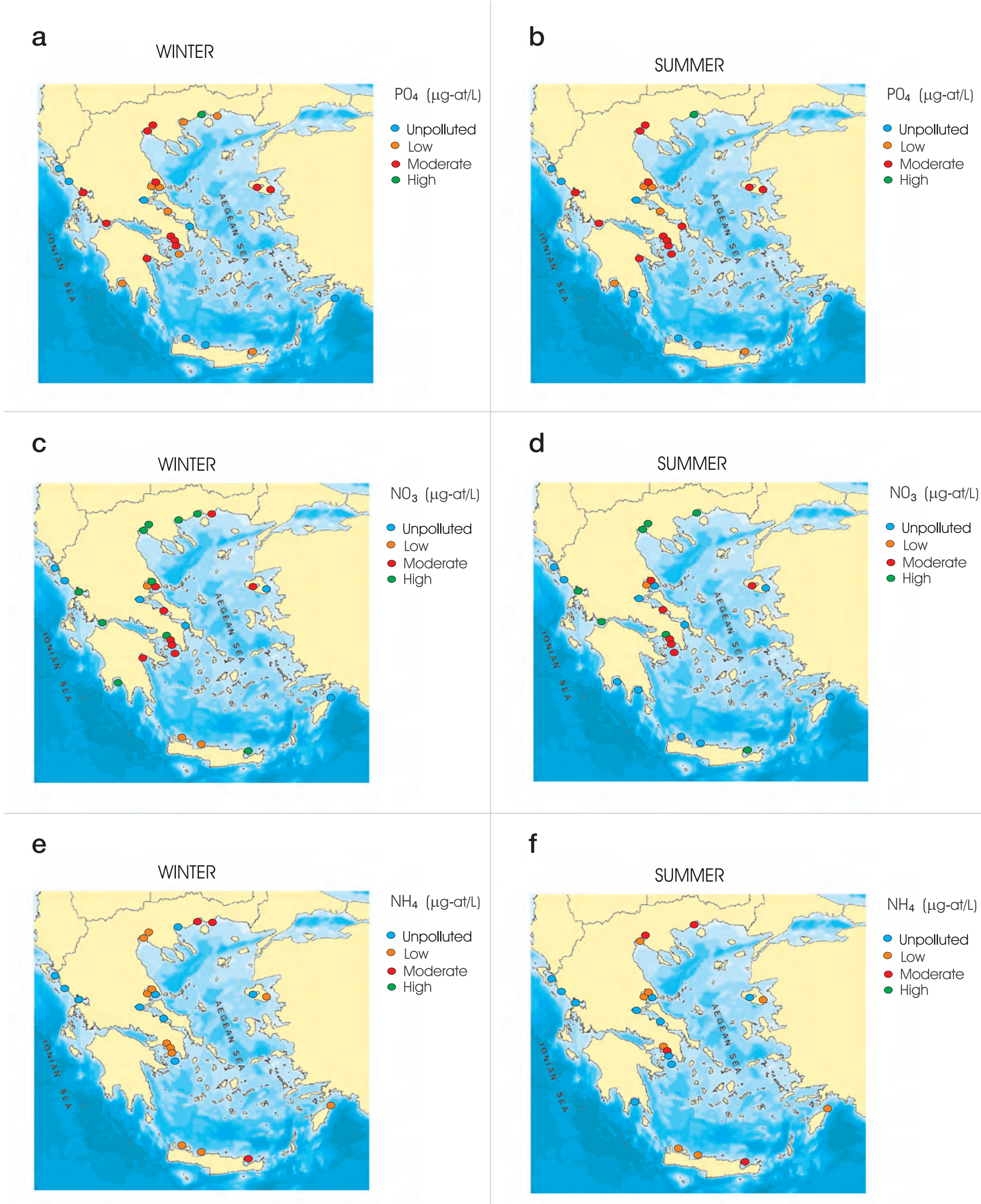


Source: *MEDPOL database (MEDPOL Project 1993-1997).*

Table IV.1: *Mean Dissolved Oxygen and nutrient concentrations in various selected Hellenic coastal areas.*

Area	DO (mL/L)		P-PO_4 (μg-at/L)		Si-SiO_4 (μg-at/L)		N-NO_2 (μg-at/L)		N-NO_3 (μg-at/L)		N-NH_4 (μg-at/L)		N:P	
	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer
Saronikos Gulf-Psyttalia Outfall [1]	5.23	4.72	0.35	0.53	2.20	2.07	0.48	0.21	1.06	0.78	0.86	1.48	7.12	5.37
Inner Saronikos Gulf [1]	5.27	4.91	0.24	0.25	2.15	1.91	0.32	0.14	1.19	0.90	0.57	0.52	9.35	6.94
Outer Saronikos Gulf [1]	5.35	5.24	0.08	0.19	2.21	2.15	0.13	0.09	1.08	1.03	0.20	0.21	16.0	19.2
Elefsis Bay [1]	5.55	3.64	0.27	0.43	3.94	7.37	0.23	0.35	1.98	1.45	0.57	0.70	13.9	8.69
Thessaloniki Bay [2]	5.59	4.52	0.42	0.54	3.44	4.37	0.30	0.31	1.21	0.93	0.99	2.03	5.42	5.31
Inner Thermaikos Gulf [2]	5.66	4.91	0.35	0.29	3.54	3.06	0.28	0.14	1.31	0.83	0.96	1.04	8.25	9.04
Strymonikos Gulf [3]	6.03		0.09		4.34		0.21		2.58		0.23		34	
Nestos R. Estuary [3]	6.51		0.10		4.69		0.07		0.98		1.21		24	
Kavala Bay [3]	5.60		0.80		5.50		0.20		2.95		1.53		5.85	
S. Evvoikos Gulf [4]	5.70	4.98	0.05	0.16	1.68	0.71	0.07	0.05	0.39	0.49			11.58	8.49
Pagasitikos Gulf – Sewage Outfall [5]	4.99	5.66	0.12	0.08	3.87	4.13	0.20	0.10	0.67	0.66	0.56	0.72	11.9	18.5
Inner Pagasitikos Gulf [5]	5.32	5.74	0.20	0.16	5.08	5.13	0.22	0.08	1.74	1.01	0.75	0.69	13.6	11.1
Central Pagasitikos Gulf [5]	5.33	5.73	0.09	0.08	3.63	3.74	0.21	0.05	0.73	0.62	0.47	0.36	15.7	12.9
Amvrakikos Gulf [6]			0.53	0.40	15.2	16.6	0.12	0.08	1.62	1.66	0.43	0.40	3.2	5.3
Maliakos Gulf [7]			0.06		6.95		0.11		0.52		0.17		13.3	
Kalamitsi Preveza [8]	5.56	5.19	0.05	0.05	1.66	1.46	0.07	0.05	0.41	0.29	0.25	0.19	13.8	10.4
Sea of Kerkyra [9]	5.33	5.70	0.05	0.05	1.57	1.35	0.11	0.07	0.31	0.30	0.26	0.20	12.6	9.57
Argolikos Gulf [10]			0.27		9.72		0.12		0.82		0.53		5.44	
Lakonikos Gulf [11]		4.86		0.06		1.30		0.06		0.42		0.27		12.5
Rodos Island [12]	4.84		0.04		1.57		0.01		0.22		0.59		20.5	
Gulf of Gera – Lesvos [13]			0.19		7.54		0.09		0.62		0.84		8.16	
Gulf of Kalloni [14]	4.45		0.25		12.0		0.09		1.19		0.50		7.12	
Irakleio Bay [15]			0.08		0.97		1.81		1.31		1.19		54	
Rethymno Bay [15]			0.05		1.18		1.32		0.59		0.99		58	
Chania Bay [15]			0.06		0.87		1.74		0.59		0.78		52	
North Evvoikos [16]			0.08		5.53		0.14		1.07		0.23		17.7	
Messiniakos Gulf [17]	5.42	5.20	0.09	0.09	2.41	1.94			2.13	0.62				
Patraikos Gulf [18]			0.30				0.10		2.37					

[1] Data for the period 1998-2002. NCMR, 2000a, NCMR, 2002
[2] Data for the period 1995-2002. HCMR 2003a
[3] Data for the period 1997-1999. PAVLIDOU *et al.*, 2002b.
[4] Data of 1996. NCMR, 1997
[5] Data for the period 1998-1999. KOLLIOU, A., 2000.
[6] Data for the period 1987.NCMR, 1989
[7] Data for the period 1991, 1994.NCMR 1992a & NCMR 1994
[8] Data for the period 1990-1991. NCMR 1992b
[9] Data for the period 1991-1992. NCMR, 1991
[10] Data for the period 1996-1999. ARCHODITSIS *et al.*, 2001
[11] Data for the period 1992. NCMR, 1992c
[12] Data for the period 1999-2001. Data from MED/POL Monitoring Program.
[13] Data for the period 1996-1997. TSIRTSIS, *et al.*, 2002.
[14] Data for the period 2000-2001. TSIRTSIS, *et al.*, 2002.
[15] Data for the period 1995-1999. Data from MED/POL Monitoring Program.
[16] Data for the period 1991. NCMR 1992a
[17] Data for the period 1998-1999. NCMR, 1999
[18] Data for the period 1995-1996. Data from MED/POL Monitoring Program



Source: *Figures based on data of Table IV.1.*

Figure IV.11: *Ecological quality of coastal areas based on seasonal (winter and summer) concentrations of PO_4, NO_3 and NH_4.*

Table IV.2: *Water quality indices according to nutrient applied to the Hellenic coastal zone.*

	Units	Category			
		Unpolluted	Low	Moderate	High
Orthophosphate	(μg-at/L)	<0.07	0.07-0.14	0.14-0.68	>0.68
Nitrate	(μg-at/L)	<0.62	0.62-0.65	0.65-1.19	>1.19
Ammonium	(μg-at/L)	<0.55	0.55-1.05	1.05-2.2	>2.20

Source: *KARYDIS, 1999.*

DISSOLVED OXYGEN (DO)

The distribution of DO in sea water is the net result of the: near equilibration of atmospheric oxygen in the surface layer, biological production due to photosynthesis and biological use of DO in respiration and oxidation of organic material.

DO measurements are performed onboard using the Winkler method as modified by Carpenter (1960), immediately after sampling, taking all the necessary precautions recommended in order to avoid any biological activity and gas exchanges.

Generally, the Hellenic coastal waters are well mixed and seriously depressed oxygen levels are unusual. Regardless of that, there are coastal areas which are stratified in the warm period and the bottom waters become isolated for six or seven months. The DO concentrations for the studied coastal areas are given in Table VI.1.

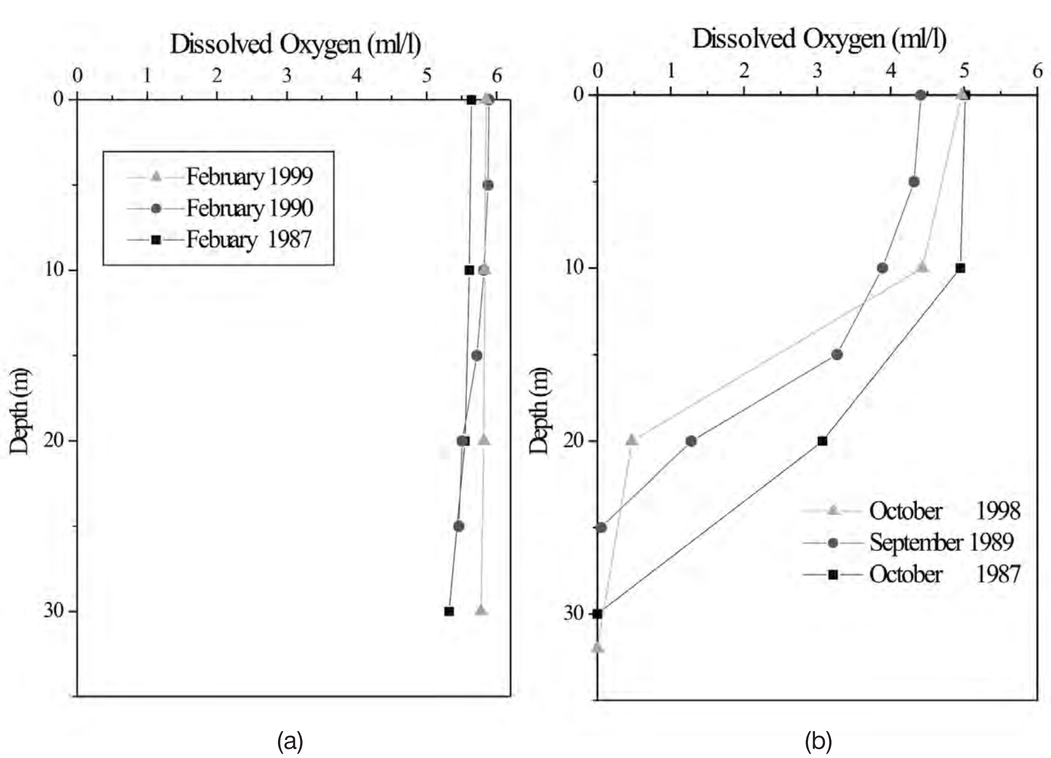
In areas where a strong thermocline prevents the mixing of surface and deeper waters, anoxic conditions occur near the bottom. Anoxia is the condition where no dissolved oxygen (DO) is available. Elefsis Bay is an example of an anoxic basin during the warm period.

During the stratification period, the complete DO depletion is observed in the deeper layer of the Elefsis Bay, usually in September or October. Figure IV.12 shows the typical profiles of DO during the cold period (a) and the warm period (b) with anoxic conditions prevailing in the bottom layer.

In Elefsis Bay, the mean integrated DO concentrations in the cold period of 1998-2002 were calculated 5.55 mL/L, whereas, during the warm period were 3.34 mL/L.

In an unpolluted coastal area such as Rodos, the mean dissolved oxygen concentration of 4.80 mL/L shows good oxygenation of the water all through the year. The water is well oxygenated during the periods of vertical mixing, with maximum values of 5.30 mL/L of DO whereas a typical stratification of the surface layers is observed in the summer months, with the DO reaching minimum values of 4.30 mL/L in the upper layers.

In a polluted coastal area such as the Kavala Gulf, the minimum DO concentration was 4.90 mL/L. The DO concentrations exhibited significant spatial



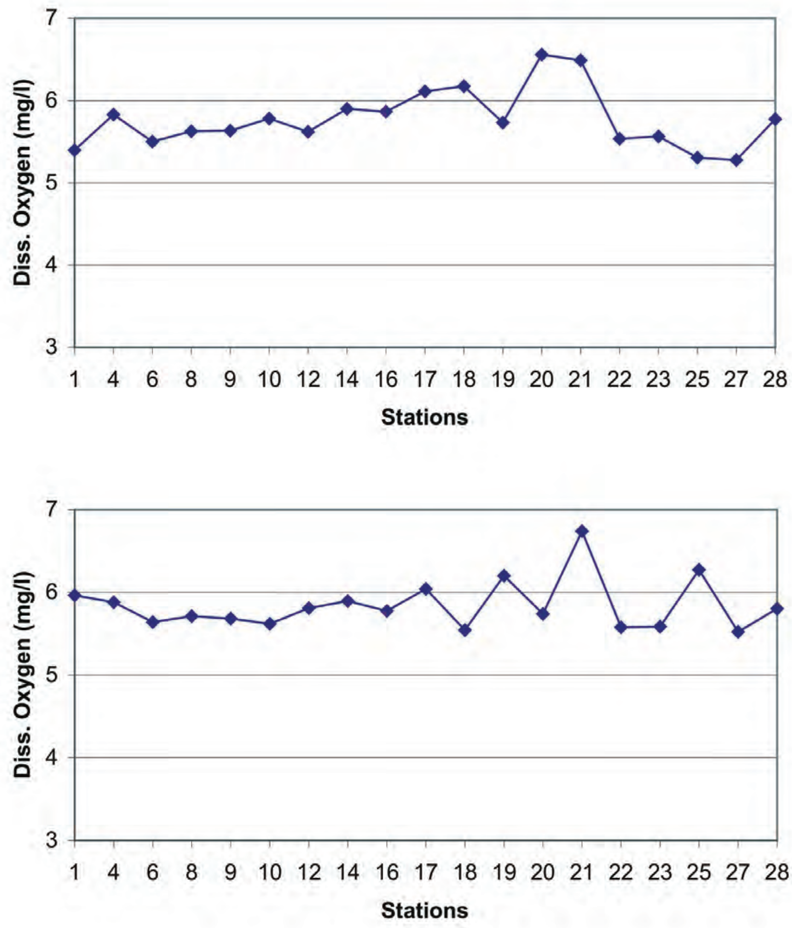
Source: *NCMR, 2000a.*

Figure IV.12: *Profiles of Dissolved Oxygen in Elefsis Bay during (a) cold and (b) warm periods.*

and temporal variability (even within the same sampling day), most probably due to the variable rate of photosynthetic activity that takes place in the water column (Figure IV.13).

In the inner Saronikos Gulf, affected by the Psittalia Sewage effluents, the DO mean integrated values ranged between 4.26 and 5.51 mL/L during the stratification period.

Figure IV.13:
Variation of dissolved oxygen in the Kavala Gulf, during a typical summer transect.



Source: *SYLAIOS, unpublished data for the period August 1997 - June 1999.*

IV.2. NUTRIENTS IN DEEP SEAS

OVERVIEW

Life at the surface of the ocean is limited by the availability of the nutrients; namely the dissolved forms of nitrogen, phosphorus and silicon. The nutrients are removed from the surface sea water by the phytoplankton via photosynthesis and are released in the deep layer via respiration and degradation of the organic matter. The general depletion of nutrients in the Mediterranean Sea compared with the nutrient content of the adjacent Atlantic waters, as well as their west to east decrease in concentrations along the different basins, is well known (Mc GILL, 1965).

The recent observations confirm the general depletion of nutrients compared with other parts of the world's oceans (SOUVERMEZOGLOU, 1989). There is a limited supply to its surface waters from both its deeper layers and external sources (i.e. Atlantic inflow, riverine discharges and atmospheric input) but the principal reason for its deficiency is related to its hydrology and circulation as a concentration basin.

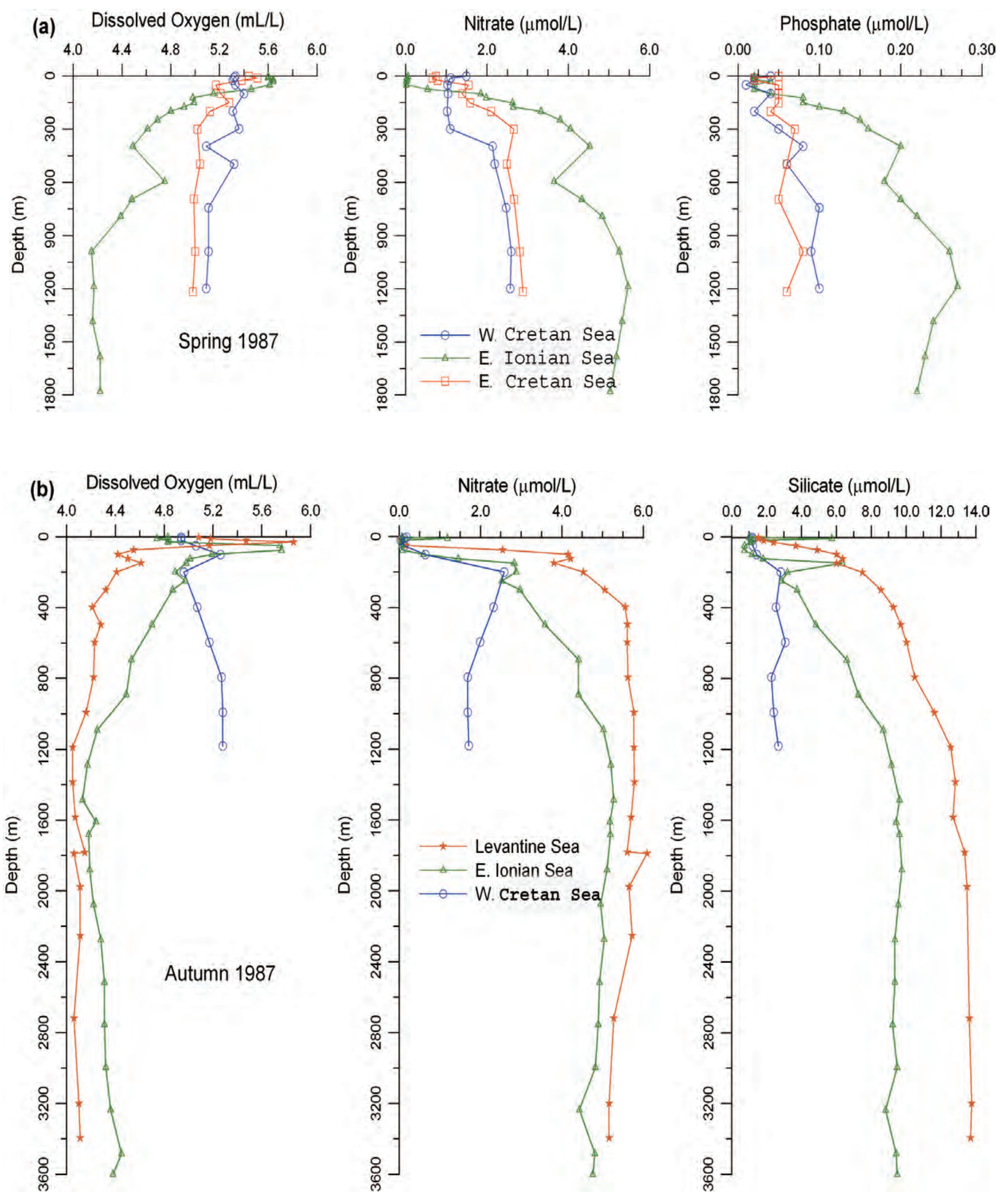
The nutrient regime of the eastern Mediterranean has been studied extensively in recent years. In the framework of national and international research programs carried out in the eastern Mediterranean during the past fifteen years 1986-2000 (POEM, POEM-BC, PELAGOS/MTP-I, OTRANTO/MTP-I, Open Sea Oceanography, MATER, INTERREG) chemical data were collected simultaneously with the physical data.

Chemical observations were made in the region comprising the north Aegean Sea, the Cretan Sea, the passages of the Cretan Arc, the northwestern Levantine Sea as well as the northeastern and southeastern Ionian Sea. The analysis of the data sets and the interpretation of the results revealed the existing analogies between the chemical and physical parameters and dynamics in the spatial distributions, as well as the signals corresponding to physical processes and the temporal variability, from seasonal to interannual.

Typical vertical distribution patterns of oxygen and nutrients in different areas and seasons from data collected in the Hellenic Seas during the POEM cruises are shown in Figure IV.14. It is evident that the nutrient levels are typical of an oligotrophic region. The surface layer totally lacks phosphate and nitrate, while it contains small amounts of silicate. The nutrient depleted surface layer is separated from the intermediate and deep-water layers by a transitional layer of 100-200 m thickness, within which the concentration of nutrients increases rapidly. The concentration of nutrients in the intermediate (250-600 m) and deep-water layers is rather constant, increasing in the following order: Aegean< Ionian < Levantine and of the same order of magnitude as reported by Mc GILL (1965). The oxygen is almost saturated in the surface layer (~6 mlL/L in winter and ~4.8 mL/L in summer); a sharp decrease of oxygen is observed in the transition layer while in the deep waters the concentrations are around 4.2 mL/L decreasing in the order which nutrients increases: Aegean> Ionian > Levantine.

PHYSICAL PROCESSES INFLUENCING THE DISTRIBUTION OF OXYGEN AND NUTRIENTS

Although the Mediterranean on the whole is oligotrophic, locally and temporary high planktonic biomasses have been measured. In the cyclonic regions (see the corresponding chapter), where the nutricline[1] ascends to the base of the euphotic zone, the phytoplankton biomass and primary production is higher than in the anticyclonic regions where the nutricline is situated at greater depths, limiting the nutrient input to the surface waters during the winter mixing (SOUVERMEZOGLOU & KRASAKOPOULOU, 1999). Taking into account the general oligotrophy of the eastern Mediterranean the role of the physical processes is especially important, as the input of nutrients from the lower layers, especially by wintertime vertical mixing, can contribute to the phytoplankton production. Other reasons related to the relatively enhanced production are: intensive convective mixing during winter leading to vertical homogenisation; upwelling of waters from intermediate layers to the euphotic zone; and nutrient enrichment in the river plume areas. Examples of the effect of the mesoscale circulation and the wintertime vertical mixing on the distribution of oxygen and nutrients in the Hellenic Seas are demonstrated below.



Source: *SOUVERMEZOGLOU & KRASAKOPOULOU, 1999.*

Figure IV.14: *Vertical distribution of oxygen and nutrients in the northwestern Levantine Sea and the adjacent Cretan and eastern Ionian Sea during (a) spring 1987 (b) autumn 1987.*

[1] important gradients of oxygen, nutrients, salinity and temperature in the subsurface layer, form the oxycline, the nutricline, the halocline and the thermocline respectively.

CHEMICAL SIGNAL OF THE MESOSCALE CIRCULATION

In order to compare the distribution of the chemical parameters in a cold and a warm core eddy, the Rodos cyclone and the Ierapetra anticyclone, different seasonal (autumn, winter and spring) cruises were chosen (Figure IV.15a and 15b).

The Rodos Gyre is a permanent circulation feature within the eastern Mediterranean, having a hydrographic structure typical of a cyclonic cold dome. The concentrations of nutrients in the surface waters around the Rodos Gyre (Figure IV.15a) are, for most of the seasons, as poor as in the other areas of the Levantine Sea. In the areas where cyclonic circulation prevails, the oxycline, the nutricline, the halocline and the thermocline are established near the surface. During the severe winter of 1992 the halocline and the thermocline disappeared completely, while the oxycline and nutricline are topped by a very thin layer poor in nutrients and rich in oxygen originating from the surrounding areas.

The concentrations of oxygen in the subsurface layer were higher than those measured during the other cruises due to the deep and intense convective mixing and the prolonged cold winter. At the 50 dbars level, within the core of the gyre the oxygen minimum is lower than 4.7 mL/L and the nitrate maximum higher than 3.5 μmol/L. The cyclonic gyre extends to the south at 100 m level and presents two distinct cores. The lower oxygen (O_2<4.5 mL/L) and the higher nitrate concentrations

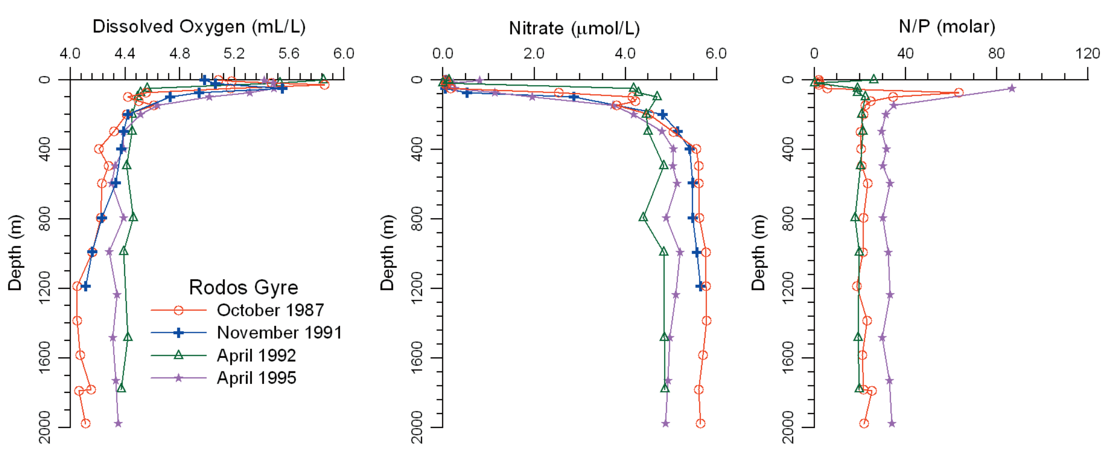
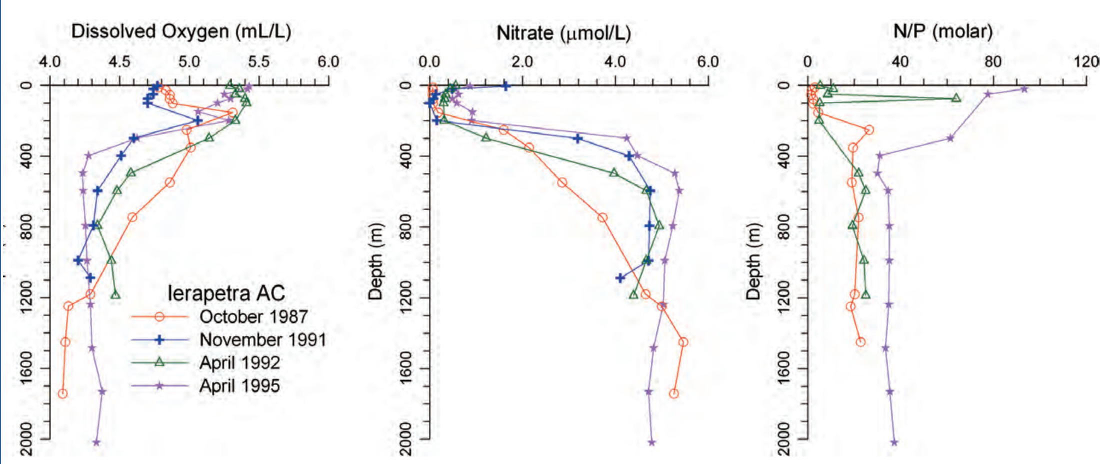


Figure IV.15a: *Vertical profiles of dissolved oxygen, nitrate, N/P (molar ratio of total oxidised nitrogen to orthophosphate) in the Rodos Gyre for October 1987 - April 1995.*



Source: *SOUVERMEZOGLOU & KRASAKOPOULOU, 1999.*

Figure IV.15b: *Vertical profiles of dissolved oxygen, nitrate, N/P (molar ratio of total oxidised nitrogen to orthophosphate) in the Ierapetra anticyclone for October 1987 - April 1995.*

(NO_3>4.5 μmol/L) appear in the centre of the northern core (Figure IV.16). In the centre of the gyre the water column below 200 m down to the deep layers is homogenised and the oxygen varies between 4.3 and 4.6 mL/L (Figure IV.14), whereas nitrate varies between 4 and 5 μmol/L. These concentrations considerably differs from those usually found in the area. In the deep layer, the increase of oxygen, salinity, temperature and the corresponding decrease of nitrate by about 0.35 mL/L, 0.1psu, 0.25˚ C and 0.8 μmol/L respectively, can be attributed to the exceptionally deep convection, down to at least 2 000 m leading to the formation of **L**evantine **D**eep Water (**LDW**), contrary to the classical LIW formation in the area (Figure IV.15.a). Nevertheless, we must take into account the contribution of **C**retan **D**eep Water (**CDW**) to the modification of the hydrochemical properties of LDW - see also chapter *'Influence of the Eastern Mediterranean Transient'*.

In the Ierapetra anticyclonic eddy, the oxycline, the nutricline, the halocline and the thermocline are established about 100 m deeper than in the Rodos cyclone. During September 1987, the Ierapetra anticyclone presented a strong signal mostly in the upper layer (Figure VI.15b). Within the gyre, surface waters down to a depth of 200 m (depth of the nutricline) are very poor in nutrients (NO_3 <1 μmol/L). The nutricline deepened to about 400 m in late winter 1992, while it was situated at about 200 m depth in October 1987, November 1991 and April 1995. The increase of oxygen and the corresponding decrease of nitrate below 1 000 m for the period from October 1987 to March 1992 can be attributed to the CDW outflow (see also chapter *'Influence of the Eastern Mediterranean Transient'*. The evolution of the hydrochemical parameters from 1987 to 1995 due to the outflow of CDW is well reflected in the layer below 1 200 m by an increase of oxygen, salinity and temperature and a decrease of nitrates by about 0.2 mL/L, 0.06 psu, 0.2˚C and 0.6 μmol/L respectively.

Deep water formation

Dissolved oxygen content in the ocean is governed by the biological activity in the water column as well as by physical processes. The surface water of the ocean usually reaches its saturation oxygen content. The ventilation of the deep basins takes place occasionally during massive water formation events. At the same time, these formation events constitute a mechanism for the direct downward transport of the inorganic and the newly formed organic matter, from the surface layer. The organic matter that reaches the bottom layer just after the deep water formation event, is rich in labile and easily oxidisable material and its decomposition leads to a significant oxygen uptake.

A characteristic example for the comprehension of this process is the dense water formation in the north Aegean Sea. Historical hydrographic data, in the north Aegean Sea, suggest that there was extensive production of dense water on two occasions during the last two decades, the winters of 1987 and 1992-1993. We had the opportunity to observe the major formation event during late winter 1987 thanks to two extensive surveys performed in the north Aegean Sea during February and

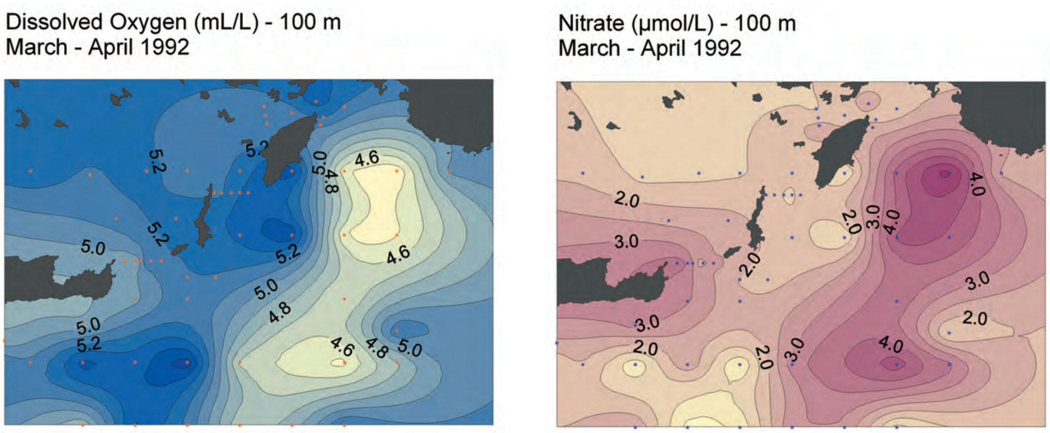


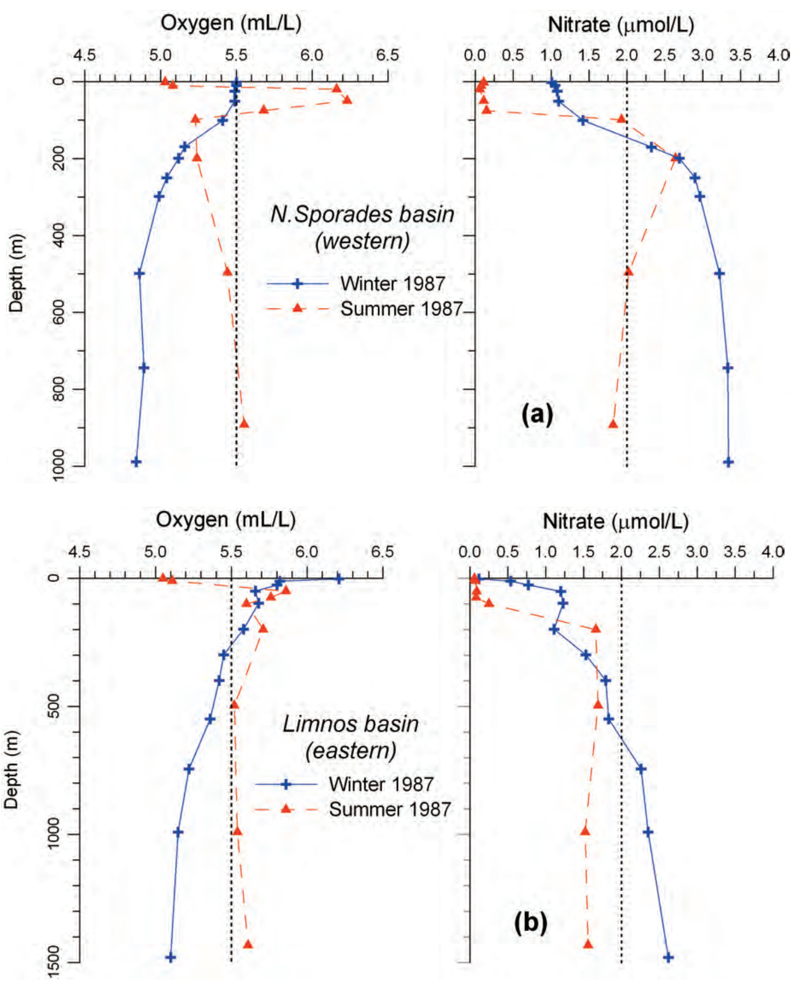
Figure IV.16: *Horizontal distribution of oxygen (mL/L) and nitrate (μmol/L) in the Rodos Gyre (100 m during spring 1992).*

Source: *SOUVERMEZOGLOU & KRASAKOPOULOU, 1999.*

August 1987 (SOUVERMEZOGLOU & KRASAKOPOULOU, 2002). The dramatic increase in oxygen content below 200 m that was recorded between February and August in two depressions of the North Aegean Trough is proof of the severity of this formation event (Figure IV.17). Furthermore, the observed increase of oxygen is followed by a corresponding decrease of the nutrients content. However, the variation of oxygen and nutrient concentrations, between the two periods, is more important for the deep layers of the North Sporades Basin (western), probably because this basin was filled with 'older' waters (lower oxygen - higher nutrient content) before the formation. The increase of oxygen in the deep layers of the western and the eastern basin is about 0.63 and 0.45 mL/L of O_2 respectively, while the corresponding decrease of nitrate is 1.39 and 0.95 μmol/L; of silicate 4.06 and 2.25 μmol/L and of phosphate 0.045 μmol/L for both basins.

Our lengthy observations showed that the degree of oxygenation and the nutrient content of the deep basins of the north Aegean Sea, differs considerably indicating the limited communication between the basins, the existence of several sources and probably the different intensity and timing of deep water formation. During the periods of isolation of the deep waters, different oxygen consumption-nutrient regeneration rates were observed in the three depressions of the North Aegean Trough.

The depth-weighted oxygen concentrations in the deep layers (depth >500 m) of the three basins (Limnos, Athos, Skyros), from March 1997 to February 1999, showed a more important decrease



Source: *SOUVERMEZOGLOU & KRASAKOPOULOU, 2002.*

Figure IV.17: *Vertical distribution of oxygen and nitrate of* ***(a)*** *the North Sporades basin and* ***(b)*** *the Limnos basin during summer and winter 1987.*

in oxygen and consequently more regeneration in nutrients, in the easternmost Limnos Basin (Figure IV.18).

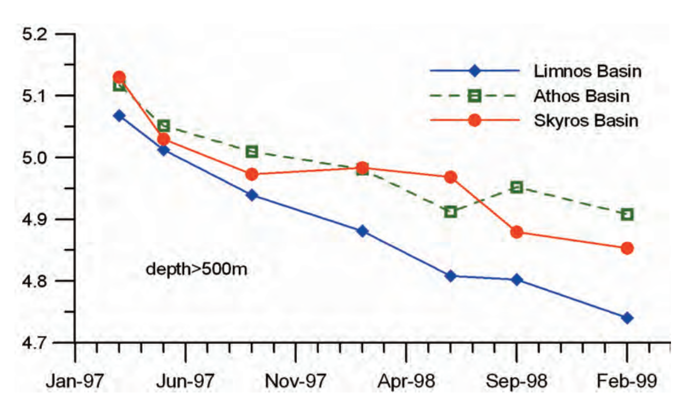
Influence of the Eastern Mediterranean Transient on the distribution of oxygen and nutrients

As it is known from previous investigations the EMDW is formed in the northern Ionian Sea by the mixing of the **Ad**riatic **B**ottom **W**ater (**AdBW**), outflowing over the sill of the Otranto Strait, with the Ionian waters moving towards the Adriatic. Figure IV.19a represents the distribution of oxygen along a section parallel to the coastline from the Ionian Sea to the Levantine Sea in September-October 1987. Our observations in the vicinity of the Otranto Strait during the cruise of R/V Aegaeo in March-April 1987, permitted the identification of the well-oxygenated and relatively nutrient-poor AdBW (in the core: O_2>5.2 mL/L, NO_3<3.0 μmol/L, PO_4<0.1 μmol/L and SiO_4<3.5 μmol/L) (SOUVERMEZOGLOU *et al.*, 1992). In summer the outflowing Adriatic water over the sill occupied a thinner layer, its chemical composition changed and became richer in nutrients and poorer in oxygen (O_2<5.1 mL/L, NO_3>3.3 μmol/L, PO_4>0.2 μmol/L and SiO_4>3.8 μmol/L) (Figure IV.19a).

In the Ionian, south of latitude 39˚ N and below 800 m, the deep waters are almost homogeneous. This water mass formed, by the mixing of the AdBW with the LIW, is the EMDW and has O_2<4.4 mL/L and NO_3>5.0 μmol/L (SOUVERMEZOGLOU *et al.*, 1992). The evolution of the nutrient and oxygen content of the EMDW from the south Ionian Sea towards the northwest Levantine is related to the decomposition of organic materials (O_2<4.1 mL/L and NO_3>5.5 μmol/L). The evolution of oxygen in the deep layer from the Ionian to the northwest Levantine Sea can be followed in Figure IV.19a. In this figure we can also observe how the oxygen pattern is affected by the presence of mesoscale cyclonic and anticyclonic gyres in the area. The contribution of the Aegean Sea in the intermediate and deep water of the eastern Mediterranean till 1987 has been considered secondary and rather sporadic. It was restricted in the vicinity of the Cretan Arc regions losing its characteristics rather quickly (SOUVERMEZOGLOU *et al.*, 1992).

The changes in the thermohaline circulation of the eastern Mediterranean at the end of the 1980s, known as the **E**astern **M**editerranean **T**ransient (**EMT**), had a strong influence on the oxygen and nutrient field in all major water masses of the eastern Mediterranean Sea. In the years following 1987, both density and transport rates of CDW were increased resulting in the addition of very dense and well-oxygenated waters to the deep and bottom sections of the eastern Mediterranean, displacing the waters of Adriatic origin upwards. The new source (Aegean) was more effective than the old one (Adriatic) since it produced not only denser but also higher volumes of water.

During 1992, large quantities of outflowing CDW lie beside the deep waters of Adriatic origin creating important gradients in the deep layer. Patches of oxygen rich-nutrient poor CDW with a lateral scale of 100 to 250 km were detected to the south of Kriti and eastward of the eastern Straits of the Cretan Arc (Figure IV.19b). By 1995 dense waters of Kriti



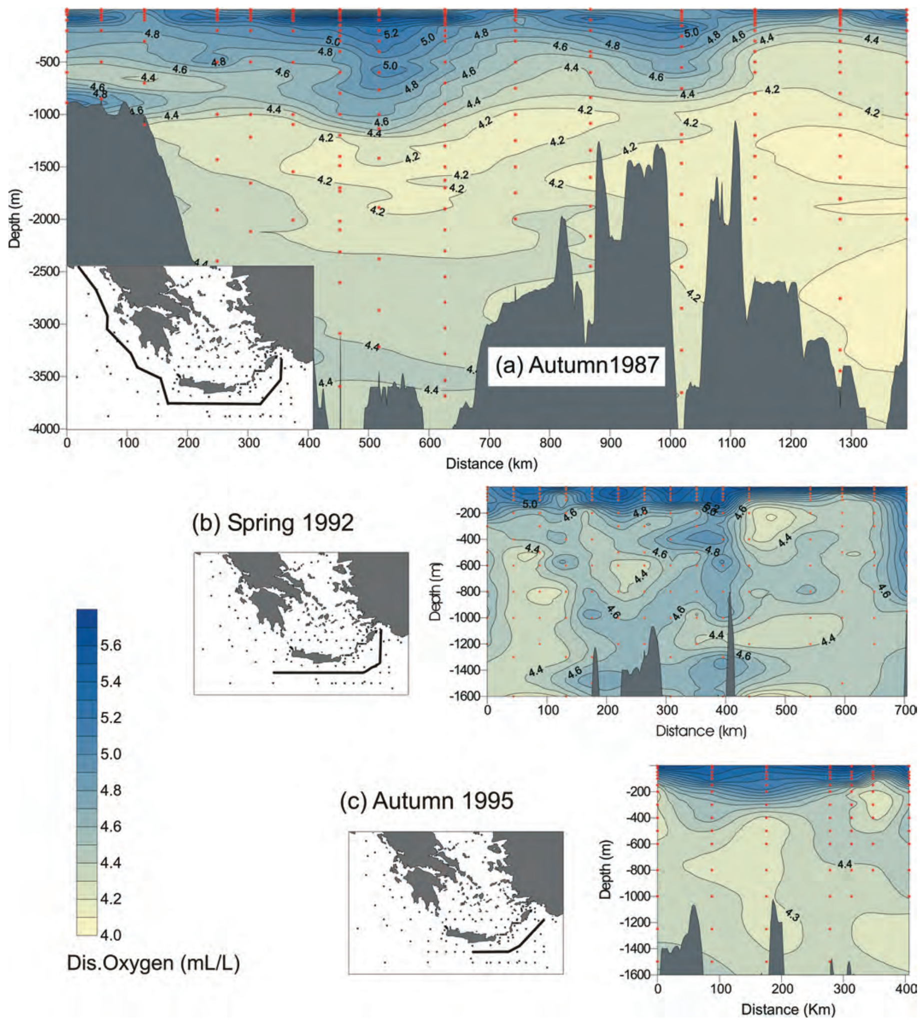
Source: *SOUVERMEZOGLOU & KRASAKOPOULOU, 2002.*

Figure IV.18:
Temporal variation of mean integrated dissolved oxygen concentrations, for depths below 500 m, in three sub-basins of the north Aegean Sea, from March 1997 to February 1999.

had filled the deepest parts of the Ionian and Levantine seas dramatically changing the properties of the deep waters.

The vertical distribution of oxygen and nitrate in 1995 totally differed from that of 1992. The water column below 400 m was homogenised (oxygen 4.3-4.5 mL/L, nitrate 3.5-5 μmol/L) (Figure IV.19c). The oxygen increase and the nitrate decrease in the deep and bottom layers of the eastern Mediterranean from 1987 to 1995 were in the order of 0.3 mL/L and 1μmol/L respectively. The old EMDW was lifted up several hundreds of metres enriching the intermediate depths of the basin with nutrients. We can assume that in some areas these nutrients could reach the euphotic layer by mixing and in this way contribute to the possible increase of biological production.

In the framework of the Mediterranean Targeted Project (MTP)-PELAGOS four seasonal oceanographic cruises were performed in the area of the Cretan Sea and the Cretan Arc Straits from March 1994 to January 1995. Our calculations for the period of these cruises showed that the mean annual CDW outflow through the Kasos Strait was about 10.8 x 10^7 tonnes of oxygen, 7.3 x10^5 tonnes of nitrogen, 5.5 x10^4 tonnes of phosphorus and 17.9 x10^5 tonnes of silica. The corresponding fluxes through the Antikythira Strait were about 4.7 x10^7 tonnes of oxygen, 2.8 x10^5 tonnes of nitrogen, 2.1 x10^4 tonnes of phosphorus and 6.2 x10^5 tonnes of silica (KRASAKOPOULOU *et al.*, 1999). The MATER cruise of October-November 1998,



Source: *SOUVERMEZOGLOU & KRASAKOPOULOU, 1999; SOUVERMEZOGLOU et al., 2000.*

Figure IV.19: *Vertical distribution of oxygen (mL/L) concentrations along the transects shown in the inset maps (a) during autumn 1987, (b) during spring 1992 and (c) during autumn 1995.*

dedicated to the monitoring of the 'Transient' in the eastern Mediterranean, allowed the identification of the evolution of the oxygen and nutrients in the Ionian, the Cretan Passage, the Levantine and the Cretan Sea. The distribution of dissolved oxygen and phosphate along the southeast Ionian - Cretan Sea - northwest Levantine Sea (through Antikythira and Kasos Straits) (Figure IV.20), show the following:

The 'oxygen poor-nutrient rich' old **E**astern **M**editerranean **D**eep **W**ater (**EMDW**) is uplifted and occupies the layer, between ~500 - ~2 000 metres in the Levantine and the Ionian basins. Below this water mass, lies the more oxygenated and poorer in nutrients (O_2 > 4.4 mL/L, PO_4< 0.2 μmol/L) old CDW which was outflowing in the beginning of the 'Transient' during 1994-1995. THEOCHARIS *et al.* (2002) mentioned, that recently the CDW outflowing from the straits is slightly less dense and equilibrates at shallower depths, between 1 000 - 2 500 m, outside the Cretan Sea. We have a clear indication of the outflow of this new CDW on the distributions of oxygen and phosphates, outside of the Antikythira and the Kasos straits at ~2 000 m (Figure IV.20). These findings are in agreement with the physical observations (THEOCHARIS *et al.*, 2002). The **TMW** (**T**ransitional **M**editerranean **W**ater) formed an 'oxygen poor-nutrient rich' distinct layer in the eastern Cretan Sea, while its signal was weaker in the western Cretan Sea (Figure IV.20).

In the same period the well-oxygenated relatively poor in nutrients water, found below the old EMDW, near the bottom of the north-eastern Ionian (not shown), give evidence that the Adriatic Sea has restarted the formation of dense water (SOUVERMEZOGLOU *et al.*, 2000). Oxygen and nutrient sections along the Cretan Passage strongly

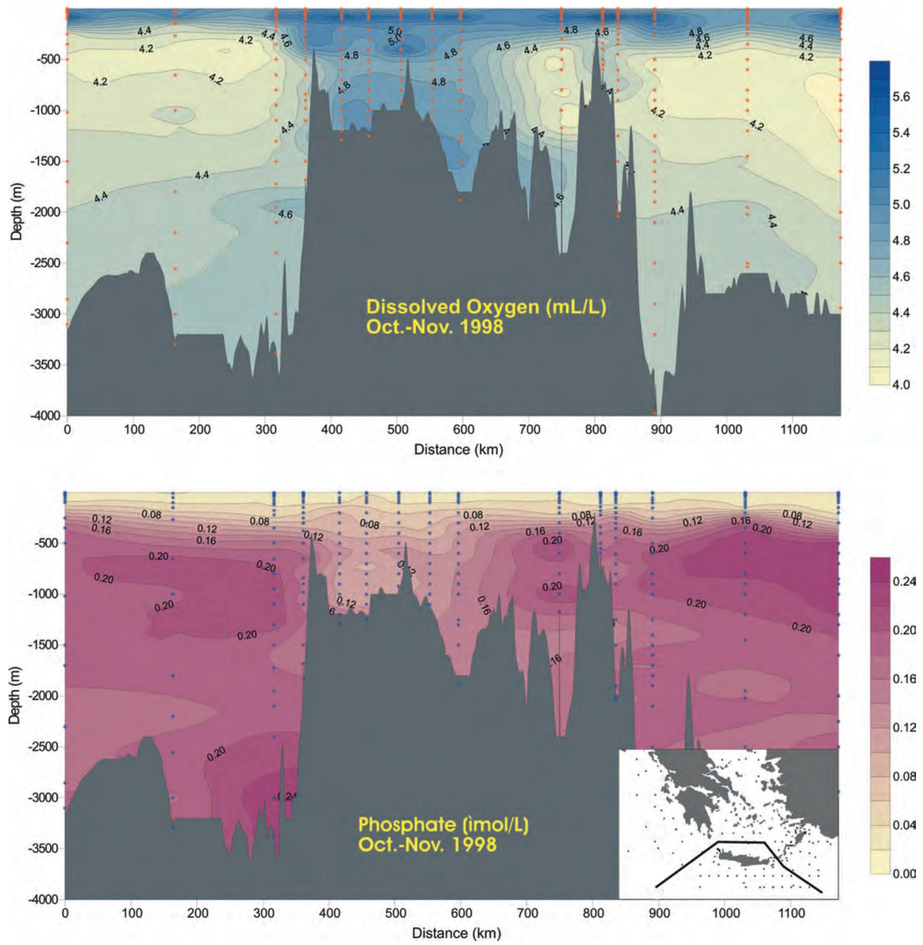


Figure IV.20:
Vertical distribution of oxygen (mL/L) and phosphate (μmol/L) concentrations along the transect shown in the inset map during autumn 1998.

Source: *MTR-II-MATER project, 1999.*

indicate the decay of the Cretan Deep Water outflow. The decrease of oxygen and the increase of nutrient content in the deep and bottom layers of the Cretan Passage and the shifting of the TMW to the deeper layers indicate that the water column structure has changed since 1995.

SUMMARY

In order to have a concrete picture of the oxygen and nutrient values usually observed in the eastern Mediterranean Sea, we have summarised the mean concentrations of oxygen and nutrients, at three depths below the transitional layer, in the different basins of the eastern Mediterranean (Table IV.3a & 3b).

The higher oxygen concentrations in deep layers of the Aegean Sea and its relative deficiency in nutrients, compared to the Ionian and Levantine seas, are clearly shown in this table. The high oxygen and low nutrient values, observed in the northeast Ionian Sea, are related to the newly formed AdBW outflow. The slightly higher nutrient and lower oxygen content of the northwest Levantine Sea, compared with the south Ionian Sea are also shown in the same table.

The Mediterranean waters, apart from their relative deficiency in nutrients, are characterised by a nitrate to phosphate atomic ratio different from that of the open ocean, in particular of the Atlantic Ocean. **Our results indicated that for the eastern Mediterranean the N:P ratio ranges between 20-28**, which is much higher than that in the Atlantic Ocean, in conformity with the Redfield's ratio N:P=16:1).

Thus the Mediterranean appears to be an exception, in that phosphorus is the most important liming factor as opposed to the other seas where nitrogen is the most important liming factor. In order to explain the high N:P ratio, several hypotheses have been proposed in the literature. The nitrogen fixation by cyanobacteria, the internal process in the basin and the phosphate removal by the absorption of Saharan dust particles rich in iron oxides, are the most probable of all of them.

It is interesting to note that the N:P ratio varies in different water masses of the eastern Mediterranean. The Ionian Sea stations near the Otranto Strait have a mean molar ratio N:P ratio of 26.4, while the ratio estimated by the slope of the linear regression at the stations located south of 39˚N is 20.9, attributed to the different proportion of AdBW and LIW in the water column of the two groups of stations that were used (SOUVERMEZOGLOU *et al.*, 1992). The mean molar ratio estimated from the slope of the linear regression analysis in the Cretan Sea is about 22 (KRASAKOPOULOU *et al.*, 1999). However, the N:P ratio in the water column varies substantially with depth. In the Levantine Sea anomalously high values (N:P > 40) were found at the top of the nutricline on the vertical distributions of the ratio of both the Rodos Gyre and the Ierapetra anticyclone during different cruises (Figures IV.15a and IV.15b). The N:P ratio is rather constant in the layer below 400 m ranging between 20 and 24 but we do not yet have any explanation for the higher values observed in 1995.

Table IV.3: *Mean concentrations of oxygen (a) and nutrients (b), at three depths below the transitional layer, in the different basins of the Hellenic Seas.*

(a)

Depth m	Cretan Sea	Aegean Sea	NE Ionian Sea	Ionian Sea	Cretan Passage	NW Levatine Sea (Rodos)
500	5.1	5.4	4.8	4.7	4.4	4.3
1000	5.3	5.2	5.4	4.3	4.2	4.2
2000	-	-	-	4.2	4.1	4.1

(b)

Depth m	Cretan Sea			Aegean Sea			NE Ionian Sea			Ionian Sea			Cretan Passage			NW Levatine Sea (Rodos)		
	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4	NO_3	PO_4	SiO_4
500	2.2	0.10	2.8	1.8	0.09	3.4	4.0	0.13	4.5	3.6	0.21	4.8	4.5	0.22	6.0	5.6	0.23	9.7
1000	1.7	0.07	1.4	2.4	0.11	4.5	2.7	0.06	3.4	4.7	0.23	8.7	4.6	0.25	9.7	5.8	0.27	11.6
2000	-	-	-	-	-	-	-	-	-	5.0	0.22	9.6	5.3	0.25	12.4	5.7	0.26	13.5

IV.3a. HEAVY METALS IN THE MARINE ENVIRONMENT

INTRODUCTION

'Heavy metals' is a general collective term applying to the group of metals and metalloids with a density greater than 6 g/cm^3. Although this is a loosely defined term, it is widely recognised and usually applied to the elements such as Cd, Cr, Cu, Hg, Ni, Pb and Zn, which are commonly associated with pollution and toxicity problems. Another name for these elements is 'trace metals' because their concentrations in various environmental compartments are usually below the level of part per million. Unlike most organic pollutants, metals occur naturally in rock-forming and ore minerals and thus there is a normal background of these elements in soils, sediments, waters and living organisms.

Trace metals in the marine environment exist in various forms. In most cases (except Fe, Al, Mn) the prevailing form of metals in sea water is the dissolved one. It includes all metal types having a diameter less than 0.45 μm. They consist of both inorganic and organic complexes.

The particulate fraction is significant in areas with a lot of suspended matter (e.g. estuaries). Trace metals are connected by various mechanisms to both suspended and sediment particles. They can be part of the lattice of various minerals, adsorbed on the surface of small grains, connected with iron and manganese oxides, connected with humic substances, etc. Their bioavailability and toxic activity are significantly affected by the way of their connection to the particles.

Some of the trace elements are required by most living organisms in small but critical concentrations for normal healthy growth (referred to as micronutrients or essential trace elements). However, excess concentrations cause toxicity. Most of the micronutrients owe their essentiality to being constituents of enzymes and other important proteins involved in key metabolic pathways.

Significant quantities of metals are introduced into the marine environment by direct discharges of industrial and domestic wastes. These inputs may be very important and dangerous locally where there is restricted water circulation.

Most rivers make a major contribution of metals into the sea, the nature of the input depending on the occurrence of metal and ore-bearing deposits in the catchment area. Increased sedimentation in estuaries traps large quantities of metals, which in turn are adsorbed on particles and are carried to the sediment.

The atmosphere is another important source of trace metals into the sea. Metals discharged into the atmosphere may exist as gases (mercury, selenium and boron) or aerosols (most of the other metals). From the atmosphere they enter the sea by gas exchange at the sea surface, by fallout of particles (dry deposition) or by precipitation (wet deposition).

The most important anthropogenic metal sources are metalliferous mining, agricultural activities, fossil fuel combustion and metallurgical industries. An important source of heavy metals, which was evaluated during the last decade, is the production of electronic devises and moreover their disposal after use. Other significant sources of trace metals are batteries, antifouling paints, additives in fuels and lubricants, dental alloys and many other items of everyday use.

In the Hellenic coastal zone, urban effluents constitute a major land-based source (LBS) of pollution. Until 10 years ago, most of the coastal area domestic wastes were discharged into the sea untreated. This practice resulted in metal accumulation in coastal sediments in areas where no other metal-related activity was present. Nonetheless, the coastal areas in industrial zones are considered as the most polluted.

The Barcelona Convention in 1976 for the Protection of the Mediterranean Sea against Pollution in combination with the International MARPOL 73/78 Convention for the Prevention of Pollution from Ships has played a beneficial role in the reduction of the pollution in the Aegean Sea. The establishment of a monitoring system for the measurement of the temporal and spatial variations of pollutants is an important result of the Hellenic MEDPOL National Programme (UNEP/MAP), which has been running for the last two decades (financed by the Hellenic Ministry of Environment and Public Works). Among the parameters measured are heavy metals in sea water, effluents, biota, sediments, suspended matter and rain water. The Hellenic Centre for Marine Research along with the Universities of Athens, Thessaloniki, Patras, Thessalia and the Aegean, and the Research Centre 'Demokritos' are collaborating on this project.

The marine areas studied in the framework of monitoring or research projects are:

The Amvrakikos Gulf in western Hellas is one of the most important protected wetlands of Hellas, which is, however, affected by agricultural activities.

The Astakos Gulf is located on the western coast of Hellas. The operation of fish farms in the coastal area affects the marine environment, particularly in the vicinity of the fish cages.

The Evvoikos Gulf is located in the central eastern part of the Hellenic mainland. In its central part there is a strong tidal current that leads to the quick transport and dispersion of pollutants. The gulf is affected by anthropogenic pollution as it receives large amounts of domestic and industrial wastes from the wastewater treatment plant of Chalkis and several industries located on the coastal zone (cement, textile, paint, food, metal-forming, shipyards, etc). In the north Evvoikos the major pollution source is located in the bay of Larymna where a ferronickel smelting plant is in operation (LARKO) with designated dumping sites.

The Gulf of Geras is a small, semi-enclosed and shallow embayment located at the southeastern part of the island of Lesvos. It is surrounded by an intensively cultivated watershed mainly with olive trees and houses, a domestic type reared livestock of about 5 500 sheep, while free grazing is kept to low levels.

The Kavala Bay is affected by the oil-platforms and a fertiliser factory that increase the concentrations of Pb, Zn and Cu.

The Korinthiakos Gulf is located at the southern part of the Hellenic mainland, separating the Peloponnisos from the mainland. The area of interest lies in the Antikyra Gulf (Voiotia) due to the contribution of bauxite to the mineral substrate and the discharges of the aluminium smelting plant located there (airborne, accidental and deliberate deposit of metalliferous slag wastes at the designated dumping site).

The Maliakos Gulf is a small gulf in the central part of Hellas and includes the estuary of the Spercheios River. The gulf receives the treated wastes from the city of Lamia as well from some industries.

The Pagasitikos Gulf is a semi-enclosed gulf situated on the western part of the Aegean Sea, north of the island of Evvoia. It is a rather shallow water body connected to the Aegean Sea through a narrow channel. The sewage treatment plant of the city of Volos, as well as the industrial park of the area, are important sources of pollution, together with fertilisers, pesticides and particulate material discharges

The Patraikos Gulf is located in the southwestern part of Hellas and receives the wastes of the city and the port of Patras. The pollution load transferred by the rivers to the gulf comes from both industrial (Glafkos) and agricultural (Acheloos) activities.

The Saronikos Gulf (mean depth ~100 m) was the receptor of untreated municipal effluents from the Athens metropolitan area for more than 30 years. From summer 1994 the Saronikos Gulf receives the primary treated effluents (domestic and industrial) from the Psittalia Treatment Plant, through an outfall positioned at 60 m depth.The operation of this WWTP has played a significant role in the reduction of pollutant levels including trace elements, especially in the inner part of the gulf. The Elefsis Bay (a shallow semi-enclosed area to the north of the Saronikos Gulf) is considered as the most polluted sub-region due to industrial activities (oil refineries, shipyards, chemical plants, food, metal, cement industries etc.) on the coastal zone.

The inner Thermaikos Gulf (mean depth ~30 m) and especially its northern part (Bay and Gulf of Thessaloniki) are the marine receptors of urban and industrial wastes from the city of Thessaloniki, along with agricultural effluents from the relevant practices taking place on the adjacent land, which includes drainage basins of rivers, streams and channels discharging into the Gulf. At the same time, in the inner Thermaikos several fishing practices and aquacultures (the most important aquaculture ground of Hellas) exist together with recreational and tourist activities concentrated along its coastline. The western coast of the inner Thermaikos Gulf is influenced by the three major river estuaries (Axios, Loudias, Aliakmon). A treatment plant with an outfall discharging at 25 m depth started operating in June 2000 in the northern part of the gulf including biological treatment of the effluents. According to sewage authorities, load removal efficiency of the treatment plant has reached 90 % for nitrogen and 50 % for phosphorus.

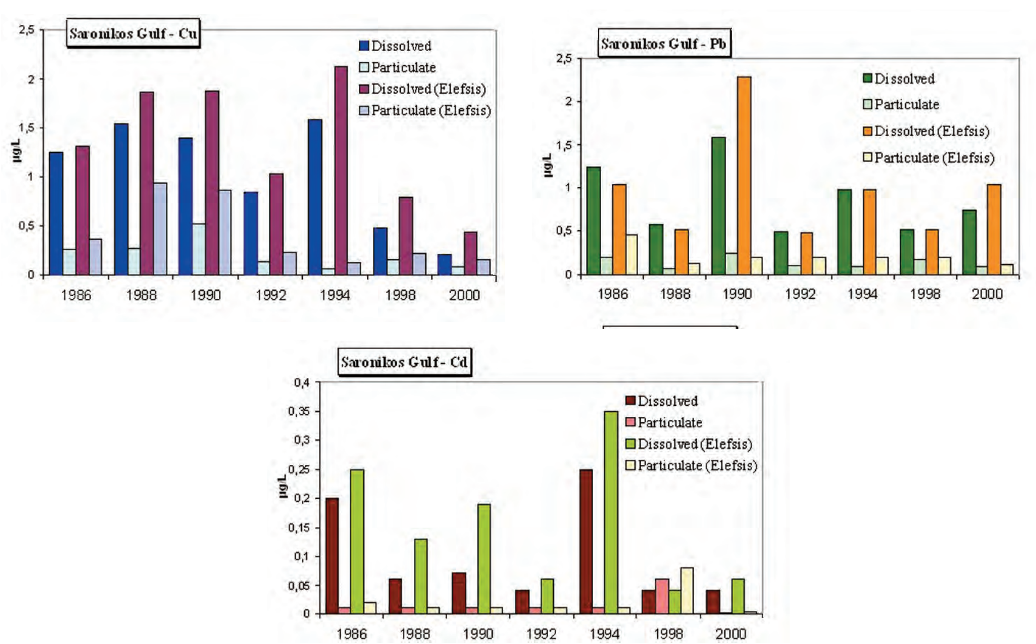
IV.3b. HEAVY METALS IN SEA WATER

Heavy metals in the water column are found either in the dissolved phase or on the suspended particles. Generally the concentrations of dissolved forms of most trace metals are higher than the concentrations of particulate forms. This is due to a) their bio-geochemical behaviour, b) their low concentrations (under the solubility levels of their salts), and c) the very low values of particulate matter in open sea. It is considered also that metals entering the sea in the particulate phase are transferred to the dissolved phase due to ion exchange activity of the main cations of sea water. Possible exceptions: Metals of main geological origin (Fe, Al, Mn), estuaries (due to high quantities of suspended material), highly polluted coastal areas (mainly from urban or industrial effluents rich in particulate matter).

The most common method for determining heavy metals in the dissolved phase is the method described by RILEY & TAYLOR (1968) and modified by KINGSTON *et al.* (1978), according to which sea-water samples are passed through columns filled with an ion exchange resin (Chelex-100, mesh 200 - 400). After removal of the alkalis the metals are eluted from the resin with a mixture of 2N HNO_3 / 1N HCl, 3:1 and the metals are determined in the eluate using the graphite furnace Atomic Absorption Spectrometry. Heavy metals in the particulate phase are usually determined after filtration of a large volume of sea water through preweighed Millipore Cellulose Acetate filters; the filters are digested with an acid mixture (HNO_3, HCl, HF) at a high temperature and the metals are measured in the final solution using the Atomic Absorption Spectrometry.

The mean values and the ranges of the metal concentrations in various marine areas are reported in Table IV.4.

Saronikos Gulf: The concentrations of metals in the dissolved phase are generally higher than in the particulate phase with the exception of Mn in the gulf of Elefsis which, is mostly enriched in the particulate form. Figure IV.21 shows the average



Source: *Data from the Athens University, MEDPOL PROJECT.*

Figure IV.21: *Average metal concentrations in the Saronikos Gulf and Elefsis Bay.*

Table IV.4: *Concentrations of trace metals in sea water.*
D: Dissolved, P: Particulate

	Cu		Pb		Zn		Ni		Cd		Mn	
AREA	***D*** μg/l	***P*** μg/l	***D*** μg/l	***P*** μg/l	***D*** μg/l	***P*** μg/l	***D*** μg/l	***P*** μg/l	***D*** μg/l	***P*** μg/l	***D*** μg/l	***P*** μg/l
Cretan Sea 1994 (1)	0.25 0.04-0.36		0.46 0.07-0.87				0.30 0.03-0.90		0.025 0.005-0.05		0.43 0.01-1.65	
Ionian Sea 2000 (2)	0.093 0.072-0.132	0.020 0.003-0.22		0.016 0.002-0.19		0.12 0.03-0.83	0.516 0.276-1.73	0.034 0.003-0.40	0.004 0.002-0.016		0.061 0.014-0.14	0.08 0.010-0.65
North Aegean Sea 1997-98 (3)	0.17 0.04-0.43	0.03 0.007-0.27		0.013 0.002-0.17		0.08 0.04-0.67	0.43 0.12-1.07	0.02 0.004-0.12	0.012 0.002-0.030	$2x10^{-4}$ $3x10^{-5}$-0.001	0.36 0.004-1.40	0.22 0.010-3.2
Saronikos Gulf 1986-98 (4)	1.19 0.10-10.7	0.23 0.02-2.11	0.83 0.03-12.2	0.14 0.005-1.2	4.6 1.0-6.48	3.1 0.43-7.1	2.00 0.15-22.5	0.62 0.04-7.10	0.10 0.008-1.2	0.02 0.001-0.2	1.36 0.10-2.2	2.85 0.01-5.5
Elefsis Bay 1986-98 (4)	1.56 0.30-9.50	0.42 0.04-8.50	0.88 0.05-11.0	0.23 0.01-3.30	6.5 2.60-9.4	3.8 0.85-9.3	2.76 0.40-41.9	0.85 0.03-18.1	0.12 0.014-2.3	0.01 0.001-0.14	3.76 0.12-13.0	6.30 0.01-230
Evvoikos Gulf 1997-98 (5, 15)	0.88 0.13-2.0	0.28 0.09-2.92	1.25 0.02-12.1	0.34 0.08-0.52	7.45 0.3-38.0	0.32 0.13-8.48			0.04 0.003-0.011			
Geras Gulf 1990-91 (6)	0.95 0.03-16.2	0.27 0.01-2.92	0.48 0.04-4.32	0.16 0.01-0.44	0.34 0.02-2.88	0.18 0.07-1.32	0.65 0.33-0.93	0.22 0.07-0.31	0.020 0.02-0.16	0.004 0.002-0.005	0.90 0.45-1.30	0.58 0.60-0.93
Patraikos Gulf 1982-86 (7)	0.73 0.23-1.92	0.25 0.04-1.10	0.51 0.09-2.25	0.15 0.04-0.47	4.70 0.80-26.5	1.85 0.40-8.90			0.30 0.010-0.65			
Thermaikos Gulf 1997-98 (8)	0.21 0.07-0.74	0.06 0.007-0.30		0.05 0.001-0.09		0.21 0.03-1.1	0.30 0.18-0.66	0.10 0.004-0.70	0.015 0.004-0.05	0.002 0.001-0.009	1.57 0.05-6.1	1.80 0.04-14.3
Amvrakikos Gulf 1982-86 (9-10)	0.62 0.13-1.62	0.29 0.05-4.70	0.37 0.04-1.10	0.22 0.06-1.74	3.34 0.54-9.9	2.44 077-14.8			0.16 0.030-0.47			
Maliakos Gulf 2000-2002 (11)	0.70 0.12-3.39	0.65 0.07-10.8	0.65 0.09-2.93	0.80 0.15-11.8	4.60 0.25-59.8	3.80 0.77-21.8	1.24 0.55-2.0	1.76 0.27-5.98	0.40 0.02-6.2	0.02 0.002-0.17	0.80 0.04-2.76	4.52 1.60-7.60
Astakos Gulf 1998-2000 (12)	1.00 0.92-1.21	0.80 0.42-1.27	1.02 0.64-1.09	0.38 0.19-0.49	11.2 7.08-16.1	7.25 3.66-9.07	0.54 0.35-0.59	0.46 0.11-0.35	1.18 0.72-1.52	0.12 0.09-0.17		
Peiraias Port 1999 (13)	0.96 0.54-1.87	1.39 0.67-2.27	1.42 0.95-1.45	1.47 0.74-2.34	12.4 7.5-17.6	2.90 1.57-5.60	1.56 0.82-1.85	0.38 0.24-0.58	0.14 0.11-0.17	0.11 0.02-0.21	2.70 1.85-3.21	1.54 0.85-2.48
Lavrio Port 2003 (14)	1.45 0.45-3.86	1.38 0.33-7.59	9.90 3.31-42.9	754 46-2326	13.0 7.5-30.7	5.56 0.18-22.1	2.50 1.43-6.45	0.50 0.16-1.17	0.25 0.11-0.35	0.13 0.02-0.60	1.46 0.97-7.41	1.88 0.46-6.98

1 VOUTSINOU *et al.*, 1997
2 HCMR (INTERREG project - unpublished data
3 ZERI & VOUTSINOU-TALIADOURI, 2003
4 Univ. of Athens MEDPOL PROJECT 1986-1999
5 DASSENAKIS *et al.*, 1999
6 DOUKAKIS, 1993
7 SCOULOS, 1987
8 METRO MED Project, HCMR
9 SCOULOS *et al., 1990*
10 SCOULOS *et al.*, 1996
11 DASSENAKIS *et al.*, 2001
12 BELIAS *et al.*, 2003
13 SAKELLARIADOU *et al.*, 2001
14 DASSENAKIS *et al.*, 2003a
15 DASSENAKIS *et al.*, 2003b

metal concentrations in the Saronikos Gulf and Elefsis Bay in both the dissolved and the particulate phase.

Recent studies in *Peiraias Port* have shown elevated concentrations of heavy metals. An example of historical pollution is the *port of Lavrio,* which, although it is much smaller than Peiraias, is an area heavily affected by industrial and more significantly by mining activities from the ancient times. Recent studies have shown extremely high Pb concentrations (Diss Pb: 9.90 μgL^{-1}, Part Pb: 754 μgL^{-1}).

Thermaikos Gulf: Trace metal concentrations diminish progressively from the inner to the outer part of the gulf (Figure IV.22). The prevailing water circulation favours the entrapment of metals close to their sources. The dissolved fraction comprised from 33 to 90% of the total metal load.

Evvoikos Gulf: Evripos Strait. The dissolved forms of metals are more important for the area, although some industries contribute to the enrichment of the sea water with particulate metals, especially Pb (FigureIV.23). Some high values were measured in samples close to industrial activities.

Maliakos Gulf: Significant seasonal variation has been observed in total metal distributions although the mean values of dissolved and particulate forms are comparable. A high percentage of particulate metals, in large particles, is entering the sea by the river runoff. The Maliakos Gulf is not a heavily polluted gulf as far as trace metals are concerned, their concentrations being intermediate between polluted gulfs and the open sea (Figure IV.24).

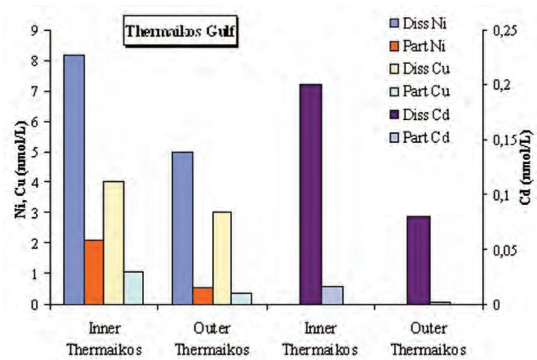


Figure IV.22:
Trace metal concentrations from the inner to the outer part of the Thermaikos Gulf.

Source: *HCMR, METRO MED Project.*

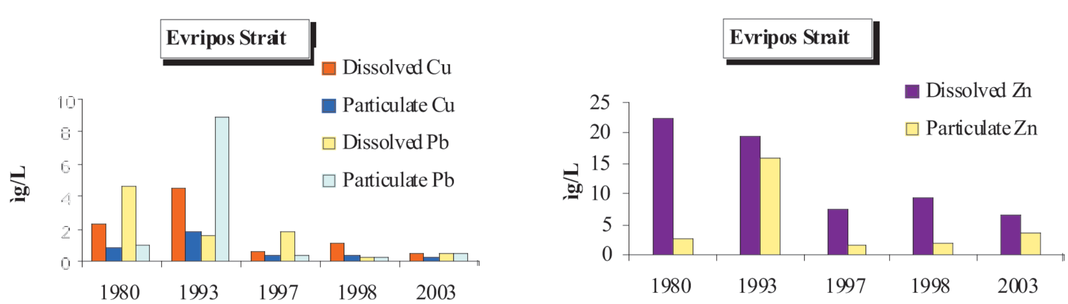


Figure IV.23:
Particulate metals in the Evripos Strait.

Source: *DASSENAKIS et al., 1999, 2003a.*

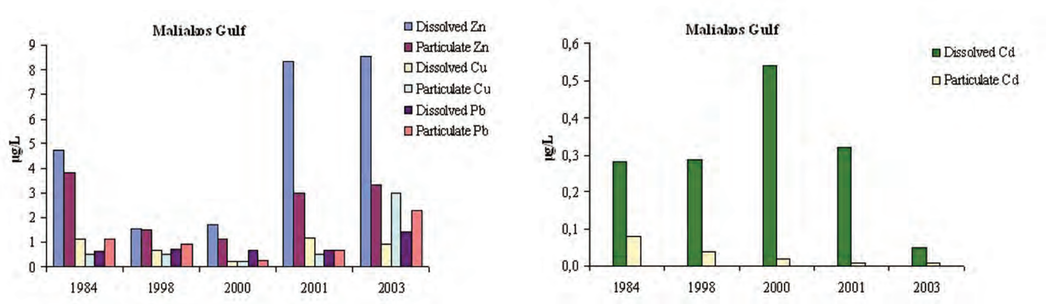
The distributions of trace metals in the *Gulf of Geras* indicate high concentrations at near-shore stations and especially near the point sources. The removal of the main pollution source in the gulf (a big tannery) has resulted in a rapid decrease of both the dissolved and particulate forms of metals.

The operation of fish farms in the coastal area of the *Astakos Gulf* affects the marine environment, particularly in the vicinity of the fish cages. A clear increase in both dissolved and particulate forms of metals is observed there, coming from the trace metal content of the fish food.

In the *Amvrakikos Gulf* most metals reach their maximum concentrations in the autumn. The contribution of the dissolved phase is significant for all metals probably due to the low amounts of suspended matter entering the gulf due to dams in Arachthos and Louros rivers.

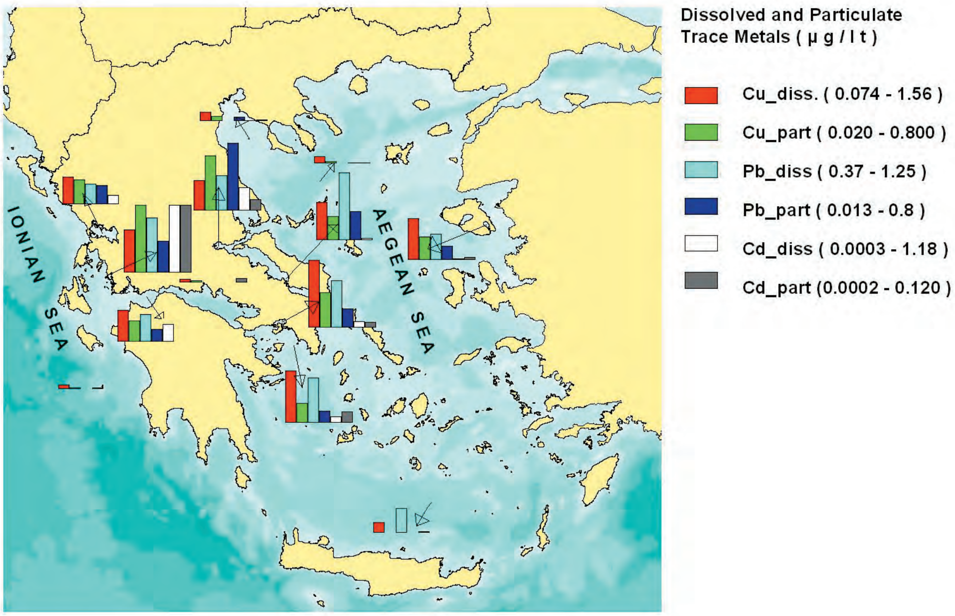
During 1982-1986 studies, the *Patraikos Gulf*, showed an increasing trend in metal concentrations.

Figure IV.25 shows the map of Hellas where the average metal concentrations for Cu, Pb and Cd, are presented for the various study areas.



Source: *DASSENAKIS et al., 2001, 2005.*

Figure IV.24: *Dissolved and particulate metal concentrations in the Maliakos Gulf.*



Source: *Data on Table IV.4.*

Figure IV. 25: *Average metal concentrations in Hellenic Waters.*

CONLUSIONS

It is generally expected that the coastal zone waters will be more enriched in trace metals in comparison to the open waters due to the vicinity to various terrestrial and/or anthropogenic sources. The ratio of trace metal concentrations in the coastal zone to those in the open waters is often called the 'enrichment factor' and is a useful tool for understanding the magnitude of trace metal enrichment in the coastal zone. Enrichment factors in relatively pristine coastal areas are only slightly higher than 1.

In an attempt to get an estimate of trace metal pollution in coastal waters of Hellas, we have calculated the enrichment factor for the inner Thermaikos Gulf relative to the north Aegean Sea (Table VI.5) based on dissolved trace metal data collected from 1995 onwards.

It is evident that the inner Thermaikos Gulf shows three fold enrichment in Cd, Cu and Ni compared to the north Aegean. For Pb, the enrichment is seven times higher, whereas for Mn the enrichment factor is less than 1. So it seems that a considerable amount of Cd, Cu, Ni and especially Pb is trapped within the inner Thermaikos Gulf.

Taking into account that trace metal concentrations do not vary significantly among the Gulfs of Hellas, as presented above, we may expect that in most cases concentrations in these areas will not exceed a tenfold increase relative to the open waters of the Aegean or Ionian Seas.

In the relevant European legislation Cd, Pb, Hg and As have been characterised as toxic, and Cu, Ni, Mn as undesirable. It should be noted, however, that the concentration values presented above are one to two orders of magnitude lower than the permissible levels set by the European Directives 80/778, 76/464, 82/176, 83/513, 84/156, 84/491 in drinking, as well as in inland, estuarine and coastal waters.

Since 1990, a general decreasing trend in trace metal concentrations has been observed in the coastal waters. This is mostly due to:

a) waste water treatment plants (WWTP) that have been established in most coastal cities;
b) the adoption by the industrial sector of 'cleaner technologies' for both production and waste management;
c) the shutdown of some old and polluting industries;
d) the fact that 'cleaner' laboratory techniques have been applied by most laboratories during the last decade, which have minimised sample contamination problems.

Table IV.5: *Trace metal enrichment factor from the inner Thermaikos Gulf.*

	Inner Thermaikos Gulf 1995-2003 (μgL^{-1})	North Aegean 1997-1998 (μgL^{-1})	Enrichment Factor
Cd	0.026 ± 0.008 (n=30)	0.009 ± 0.003 (n=402)	2.8
Cu	0.480 ± 0.050 (n=24)	0.158 ±0.044 (n=402)	3.0
Mn	3.24 ± 0.872 (n=12)	4.63 ± 0.140 (n=402)	0.69
Ni	0.964 ± 0.098 (n=20)	0.386 ±0.116 (n=402)	2.5
Pb	1.27 ± 0.080 (n=12)	0.183 ± 0.076 (n=402)	6.9

IV.3c. HEAVY METALS IN SURFACE SEDIMENTS

Marine sediments are important carriers of heavy metals in the hydrological cycle. They gather or release them into the surrounding waters. Hence, they can reflect the current quality of an aquatic system. Marine sediments naturally contain different quantities of metals, so 'background values' cannot be as readily established as for other parameters. Heavy metal concentrations of marine sediments, which have not been affected by anthropogenic influence, can be considered as background ones. The world averages for unpolluted regions presented in the bibliography depict wide ranges of concentrations and cannot be used for comparisons between different regions or for the estimation of the pollution degree of a region. Hence, the need for the determination of background concentrations of a region is very important and allows the estimation of the enrichment factor of this region. Moreover, the analysis of coastal sediments can give the 'anthropogenic fingerprints' on the bottom deposits, since they are important hosts for pollutant heavy metals.

In the Hellenic coastal zone, urban effluents constitute a major land-based pollution source. Until ten years ago, most of the coastal cities/towns lacked wastewater treatment facilities and discharged their effluents into the sea without any treatment. Untreated effluent released into the sea has resulted in some metal accumulation in harbour and coastal sediments of areas where no other metal-related activity was present. Nonetheless, the areas where industrial activities are present are still the ones considered the most polluted. For example, the industries in the city of Volos cause a slight enrichment of the values of Cr, Ni, Zn, Cu and Pb in the surface sediments of the Pagasitikos Gulf. In the adjacent north Evvoikos Gulf, a Fe-Ni alloy smelting plant causes heavily enriched values of Fe, Cr, Ni, Mn, Zn and Co. In Kavala Bay, the oil-platforms and the fertiliser factory have raised the amounts of Pb, Zn and Cu. Surface sediments in Elefsis Bay, show heavy metal pollution of Cr, Zn, Cu, Pb and Cd, due to the influence of industrial effluents. Domestic wastes from the greater Athens area discharged into the Saronikos Gulf affect metal distribution in the surface sediments of the gulf to a lesser extent. A general distribution of metal concentrations in surface sediments of the Hellenic Seas is depicted in Figure IV.26 and summarised in Tables IV.6 and IV.7.

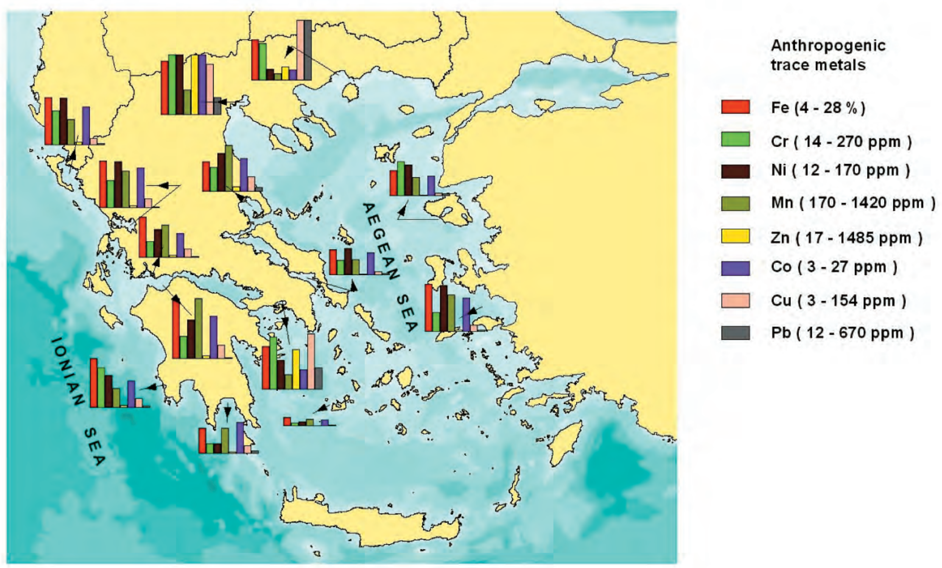
In recent sedimentary deposits, trace metals can generally be divided into two categories according to their predominant source of origin, either as 'lithogenic' often simply referred to as 'geochemical' and 'anthropogenic' known also as 'civilisational'.

For the assessment of trace metal pollution in sediments it is the anthropogenic fraction which is of prime interest and the analysis of the non-residual fractions will often yield more data on the extent of trace metal pollution than will that of the total sediment which includes the lithogenic, or non-polluted, fraction and so may mask the relationships sought.

The most commonly used method for the determination of the anthropogenic fraction of metal in marine sediments is the leaching with dilute HCl, whereas the determination of total metal concentrations requires digestion of the sediments with stronger acids (e.g. HNO_3, HF). Both cases are coupled with Atomic Absorption Spectrophotometry for the measurement of metal concentrations.

A characteristic example of anthropogenic influence concerning heavy metal pollution is the LARKO case. The result of the long term (more than 20 years) operation of a Fe-Ni alloy smelting plant is the formation of a Fe-Cr-Ni deposit on the sea floor of the north Evvoikos Gulf, which covers an area of about 45 km^2. The deposit has been formed by the continuous discharge of slag from the smelting plant and its subsequent leaching by sea water, which resulted in a partial removal of Al_2O_3, MgO and CaO and a further enrichment in Fe, Cr, Ni and Co. The leaching of the slag by sea water is probably promoted by the presence of FeS, the oxidation of which should lead to the formation of sulphuric acid (H_2SO_4) forming an acid environment around the slag. The ore deposit shows enrichment factors of 22 for Fe, 70-100 for Cr, 7-10 for Ni, 7 for Co and about 4 for Mn and Zn, when compared to unaffected sediments of the same area. This is clearly depicted in Figure IV.27.

Table IV.7 displays metal concentrations in unpolluted Hellenic areas, whereas in Table IV.8 metal concentrations in the areas considered most polluted are presented. The concentration values presented in the tables have been produced either by HCl leaching and are referred to as 'anthropogenic', or by strong acid digestion and are referred to as 'total'.



Note : The bars on the map represent normalised concentration values ranging from 0 to 1.

Figure IV. 26: *Heavy metals distribution as estimated from measurements of the anthropogenic component (mean values over the year).*

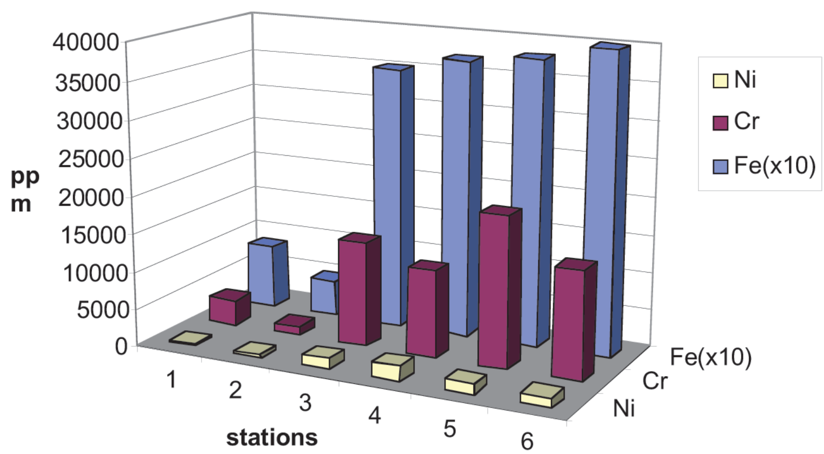


Figure IV. 27: *Stations 1, 2 correspond to unaffected sediments from the Fe-Ni smelting plant. The enrichment of stations 3 to 6 in heavy metals is obvious.*

Table IV.6: *Total metal concentrations in surface sediments (mean values) in Hellenic Seas. The polluted areas are shaded.*

	Fe %	Cr ppm	Ni Ppm	Mn ppm	Zn ppm	Co ppm	Cu ppm	Pb ppm	Source
Argostoli G. Kefallonia	1.53 0.2-3	90 1-205	47 6-106	291 65-512		7 1-24	18 4-45	26 2-206	1
Astakos Gulf	3 0.4- 4	166 63-324		687 307-969		29 38-44	23 3-35	28 14-60	11
Ithaki G.	2.3 0.9-4	255 117-383	128 102-150	1538 1100-1900		16 6-28	41 11-55	54 22-106	1
Korinthiakos G	3.15 2.5-4.2	109 84.8-139	109 91.4-137	1070 787-2407	69.3 58.4-88.4	18.1 15.2-24.8	43 36-58.8	14.4 10.7-18.9	10
Kavala Bay	14 8-26	105 20-278	22 11-47	273 65-417	67 24-90	5 0-10	16 4-24	30 5-36	11
Leros Island	7 5 –9	133 116-148	73 57-81	342 248-418	188 125-304		79 57-121	88 40-182	9
Geras Gulf (Lesvos island)	3	723	318	1309	134		29	56	2 / 11
Milos Island	3	119 63-167	61 37-83	1685 337-3318	325 231-443		51 42-68	151 60-239	4 / 11
Thessaloniki G	5 4-7	201 188-368	102 101-201	945 425-1456	218 166-1006		58 46-198	50 40-115	6
Thermaikos		235	160		103		28	37	11
Pagasitikos	7	401 334-526	174 113-233	1485 822-2514	172 147-226		72 49-117	60 27-112	5 / 11
Elefsis Bay	-	-	-	844	385		140	-	8 / 11

Source: *see sources Table IV.8.*

Table IV.7: *Metal concentrations (anthropogenic fraction) in surface sediments (mean values) in Hellenic Seas. The polluted areas are shaded.*

	Fe %	Cr ppm	Ni ppm	Mn ppm	Zn ppm	Co ppm	Cu ppm	Pb ppm	Source
Amvrakikos	22 5-30	125 27-177	131 33-188	870 323-3820	62 12-80	18 4-30	24 2-31	12 7-21	11, 12
South Evvoikos	12 6-15	66 37-97	76 25-144	370 150-800	36 9-44	10 4-15	9 3-15	20 12-38	2 / 3
Kerkyra Straits	22 6-34	154 35-257	132 31-192	599 212-1400	67 21-94	67 2-28	18 3-30	16 7-24	11
Lakonikos Gulf	12 7-17	44 26-58	28 14-40	598 121-2214	41 22-52	14 8-21	20 7-30	32 6-45	11
Lesvos Island	12 3-21	155 40-247	89 20-315	447 172-1126	32 18-43	9 0-19	8 3-12	28 10-39	2 / 11
Mesolongi Lagoon	19 10-28	73 56-112	80 40-112	764 470-1380	60 30-80	11 6-16	23 8-34	12 6-17	11
Milos Island	4 3-6	14 10-19	12 6-21	170 113-251	17 15-18	3 2-4	3 2-4	2-75	4/ 11
Navarino Bay	23 2-30	180 12-251	91 8-123	460 243-600	62 7-81	12 4-15	23 0-32	19 2-28	11
Patraikos	28 16-32	100 55-119	110 60-132	1420 750-2610	72 43-88	19 11-23	35 16-43	16 11-20	11
East Aegean	22 14-33	86 52-157	131 39-291	861 280-2640	38 7-55	15 8-24	17 4-29	17 11-32	7 / 11
Elefsis Bay	20 8-27	235 50-390	82 70-120	351 230-760	990 100-1680	9 7-12	142 20-230	240 40-400	8 / 11
Thermaikos	25 14-33	270 140-390	170 105-290	580 295-1340	1485 74-2600	27 19-37	130 28-200	195 28-330	11
N. Evvoikos LARYMNA	152 30-254	6247 250-12000	1655 300-3550	2023 1140-4560	203 46-320	119 30-212			11
Kavala Bay	19 12-26	168 50-278	33 30-47	171 65-417	345 110-510	5 2-10	154 45-226	670 322-908	11
Pagasitikos	14 8-19	110 50-150	107 32-228	1090 280-2790	115 38-135	15 8-25	38 9-39	45 19-53	5 / 11

Source : ***1.*** *ALEXANDROPOULOU et al., 1995.* ***2.*** *ALOUPI & ANGELIDIS 2001,* ***3.*** *ANGELIDIS & ALOUPI 2000,* ***4.*** *KARAGEORGIS et al., 1998,* ***5.*** *KARAGEORGIS et al., 2002,* ***6.*** *KARAGEORGIS et al., 2004,* ***7.*** *MED-POL Project 1993-1997,* ***8.*** *SCOULLOS et al., 1995,* ***9.*** *SIOULAS et al., 1998,* ***10.*** *VARNAVAS et al., 1986,* ***11.*** *VOUTSINOU-TALIADOURI, 1995.* ***12.*** *VOUTSINOU-TALIADOURI, 1989.*

In Figure IV.28 metal concentrations are presented from areas affected by hydrothermal activity in the Hellenic Volcanic Arc such as the Island of Santorini. Tectonic activity and hydrothermal processes taking place in the sea bed are considered natural sources of metals for surface sediments.

The study of metal concentrations and distribution in marine sediments has been proven as a valuable tool for environmental investigations as far as pollution is concerned. The continuous monitoring of certain areas which are subjected to different pollution sources (i.e. domestic and industrial wastes, agricultural, river runoff, etc.) is highly recommended, since marine sediments act as fingerprints of the environmental changes.

During the last 20 years a great amount of information has been obtained on heavy metal distribution in the marine sediments of the Hellenic coastal environment. Most of the research done was focused on areas with increased anthropogenic activities such as the Thermaikos Gulf, the Saronikos Gulf and Elefsis Bay, and the Evvoikos Gulf as well as the Gulf of Gera at Lesvos Island. Therefore, the continuance of scientific monitoring at the areas mentioned above and their commencement at other less affected areas will help us obtain a more detailed picture of the environmental status of the Hellenic coastal zone in both time and space.

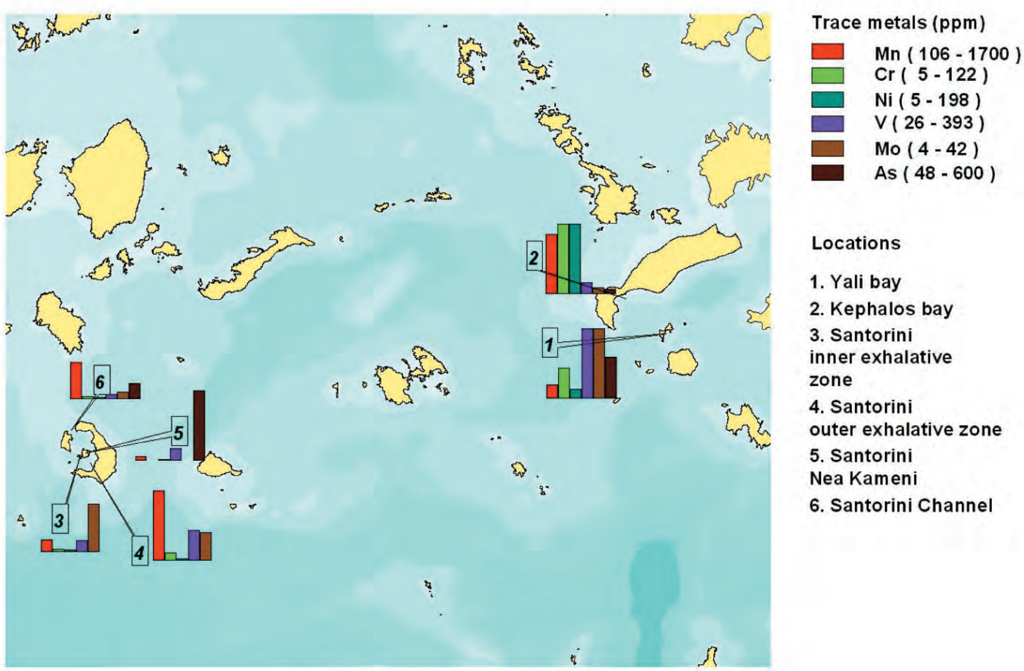


Figure IV.28: *Metal concentrations in sediments with hydrothermal activity.*

IV.3d. HEAVY METALS IN BIOTA

Contaminant determination in biota provides useful information on the marine environmental quality and the suitability of edible species for consumption (BRYAN, 1976). Prior to the assessment of high metal values in various biota samples, as an indication of marine contamination/pollution, it is recommended to clarify the influence on them of the sediment metallic background levels. As such an example, is cited here the higher Cr levels of Larymna Bay and Geras Gulf (Lesvos Island) biota since they live in the vicinity of rocks rich in Cr.

Several other parameters influence metal bioaccumulation in biota i.e. environmental/climatic ones as sea water quality, sea water temperature and salinity, currents, etc. and biological ones such as species, sex, age/size, reproductive stage, etc. (PHILLIPS, 1976). In addition, the natural (inherent) variability of metal bioaccumulation within the specimens of a population is often very important (LOBEL *et al*., 1991).

The present report is based on data originating from the laboratory of ecotoxicology of the HCMR and the Hellenic MED.POL data base. Their origination from different laboratories probably bears risks, since no intercallibration tests were effectuated. Consequently, in order to avoid overestimation of metal differences in biota from the various Hellenic areas, all the above factors are to be seriously considered.

Data concern metals' concentration in organisms such as mussels *(Mytilus galloprovincialis)*, limpets *(Patella* sp.*)* and red mullets (*Mullus barbatus*) abundant in Hellenic Seas and commonly used in environmental monitoring programs world wide.

Although emphasis is given to the more toxic metals like mercury (Hg), cadmium (Cd) and lead (Pb) that are not essential for life, information is also provided for other metals such as copper (Cu), chromium (Cr), nickel (Ni) zinc (Zn), etc. which in high concentration levels become toxic for organisms.

METALS IN MUSSELS

Results of about 1 200 composite samples, collected between 1993 and 2002, from ten Hellenic gulfs and coastal areas, were used for this report. The datasets from the Saronikos and Thermaikos gulfs are very large, including seasonal values for several years. Although the other datasets are smaller, we assume that with some exceptions, they satisfactorily represent the metal content of the local mussel populations.

The measured metal values in mussels from the above regions (Table IV.8) follow the lognormal distribution and their levels could be considered as comparable to similar ones from other non-polluted Mediterranean areas (COIMBRA *et al*., 1991, RODRIGUES *et al*., 1995).

Mercury ranged from 0.04 to 1.36 μg/g dry weight, which corresponds to about 0.009 to 0.300 μg/g fresh weight, that is well below the Hellenic and EU permissible limit of 0.5 μg/g fresh weight. Cadmium is generally low (0.017 to 8.57 μg/g dry weight corresponding to 0.004 to 1.90 μg/g fresh weight). However, some measured values exceeded the legal limit of 1.0 μg/g fresh weight:

Table IV.8: *Metal concentration in mussels from Hellenic seas (in μg/g dry weight).*

	Hg	Cd	Cr	Cu	Ni	Zn	Fe	Mn	Pb
N	121	812	1005	1061	1078	1037	1013	917	428
Average	0.29	1.03	3.98	6.14	4.16	157	76.8	10.97	5.99
STD	0.22	1.15	4.39	2.85	4.33	96.8	240	7.20	5.81
Median	0.24	0.72	2.74	5.53	3.36	136	177	8.64	2.22

Source: *Hellenic MED-POL data (1993-2002).*

3% of the Cd data exceed it slightly and about 2% exceeded it more. Lead levels varied from 0.034 to 22.0 μg/g dry weight (0.075 to 4.900 μg/g fresh weight) in 25% of the cases exceeding the permissible limit of 1.0 μg/g fresh weight. We must, however, notice that these high levels were recorded in mussels collected in the vicinity of LBS from the Saronikos and Pagasitikos gulfs and are not used for consumption.

Copper maximum levels (24.87 μg/g dry weight or 5.51 μg/g fresh weight) are below the permitted concentrations for food in Australia (10.00 μg/g fresh weight.; REILLY, 1991), while less than 1% of the zinc values were higher than the legitimate limitations for consumption in Australia (150 μg/g fresh weight; REILLY, 1991). For the remaining metals nickel, chromium, iron and manganese very little information exists for relative legislation.

The measured metal values varied according to the mussel sampling area (Figure IV.29). In comparison with other Hellenic areas, mussels from the Pagasitikos Gulf presented the highest or had among the very highest levels of Cu, Cr, Zn, Fe, Pb. This gulf has probably high background levels, since elevated metal determinations were found in superficial sediments. The Thermaikos Gulf seemed more contaminated by Hg and Mn and less affected by Cd, Cr, Zn. Exceptionally high levels of Ni, Fe and Cr were presented in the mussel samples collected from Larymna Bay due both to the functioning of the ferronickel plant and the higher background levels.

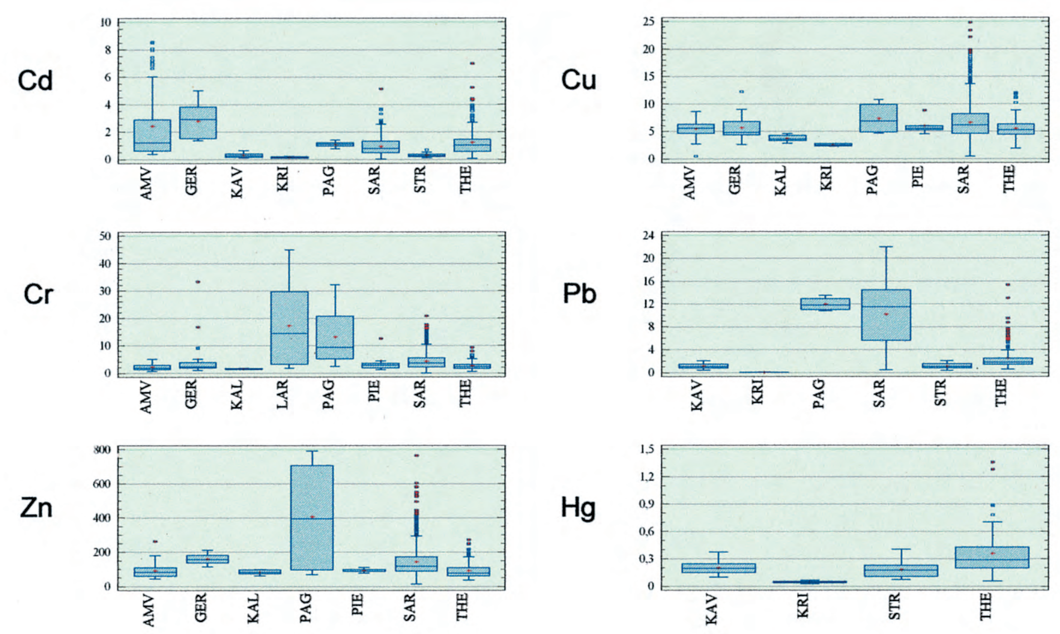
Kriti Island was found to be among the less metal-contaminated areas.

METALS IN LIMPETS

Data for limpets (*Patella sp.*) were available for nine Hellenic coastal areas: Kerkyra Island, Lesvos Island, Larymna Bay, north Evvoikos, Lavrio, Pagasitikos and Saronikos gulfs, Rodos, Santorini Island and Milos Island.

The results of the analysis for metals of about 450 composite samples collected between 1988 and 2000 from the studied areas are shown in Table IV.9.

The average metal values in limpets can be considered generally as low (CAMPANELLA, 2001). Although these gastropods are comestible, they are rarely consumed in Hellas; consequently their metal content is used rather as element for the



Note: AMV=Amvrakikos G.; GER=Geras G. (Lesvos isl.); KAV=Kavala G., PAG=Pagasitikos G.; SAR=Saronikos G.; KRI=Kriti; STR=Strymonikos G., THE=Thermaikos G; KAL=Kalloni G. (Lesvos isl.); PIE=Pieria coast.

Figure IV.29: *Box and Whiskers plots of metal concentration values in mussels from Hellenic seas. (in μg/g dry weight).*

characterisation of the coastal marine areas, than as an element for consumption suitability.

The distribution of metals in limpets from the various Hellenic coastal areas is not uniform. Table IV.10 shows summary statistics of the measured metal values in limpets.

Generally, samples from Lavrio (ancient silver mining site) exhibited the highest Cu and Zn levels. This is obviously due to the by-products of silver extraction accomplished in the past, rich in several metals such as Pb, Zn and Cu, which still remain in the coastal zone of Lavrio. Elevated Cu values can be attributed to the industrial activities of this area. The highest Cr, Ni and Fe concentrations present in samples from Larymna Bay (Table IV.10) are in accordance with other studies and are attributed to a ferronickel smelting plant operation. The limpets coming from the Saronikos Gulf contained Ni in high proportions. The data from Santorini Island show the lowest values recorded in this study indicating a relatively pristine marine environment. Finally, the samples collected in the Pagasitikos Gulf had high Zn and Mn concentrations that are consistent with the high levels in sediments, which in turn, are due both to background levels and human activities. Particularly, the abundance of Mn was probably related to the biogenic phase of the sediments.

METALS IN FISH

Fish are widely used as bioindicators for metal marine pollution. The present report is based on red mullets *(Mullus barbatus)* metallic levels, collected from ten Hellenic marine areas. The results of the analysis for metals of about 1 200 samples collected between 1990 and 2000, are presented in Table IV.11.

Mullus barbatus is a common commercial species in Hellas. Mercury content, barely measured in its tissues, varied between 0.03 and 0.05 μg/g dry weight, that is well below the permissible limit of 0.5 μg/g fresh weight

Table IV.9: *Metal concentration in limpets from Hellenic seas (in μg/g dry weight).*

	Cd	Cr	Cu	Ni	Zn	Fe	Mn	Pb
N	198	308	310	239	305	209	195	119
Average	6.55	7.55	9.30	17.68	57.1	1387	11.52	38.53
STD	3.13	7.46	3.27	11.72	29.3	1554	15.65	18.82
Median	6.37	5.35	8.88	15.25	54.4	1013	8.33	34.90

Table IV.10: *Metal levels (mean, STD, range) in limpets Patella sp. (in μg/g dry weight).*

Area	Cu	Cr	Ni	Zn	Fe	Mn
Kerkyra	7.96±2.13	3.94±1.81		58.5±9.8	1732±654	
N=38	(4.24-14.7)	(1.49-9.17)		(33-75)	(949-3959)	
Lesvos	4.28±3.65	3.65±1.81	9.40±3.52	45.5±4.4	603±230	24.14±20.26
N=7	(0.29-9.26)	(0.87-5.99)	(4.02-15.44)	(42-51)	(442-867)	(12.24-47.53)
Larymna	7.91±4.24	25.22±15.97	15.61±6.97	55.7±15.7	4574±2522	
N=86	(3.3-34.3)	(2.38-77.22)	(5.89-35.25)	(37-97)	(965-11289)	
Lavrio	13.72±2.67	8.98±6.38	6.57±1.85	302.2±64	1256±190	
N=6	(9.68-16.4)	(4.83-21.85)	(3.38-9.8)	(249-412)	(967-1416)	
Milos	9.63±3.87	5.69±4.18	20.20±14.32	45.1±21	291±42	13.14±10.62
N=69	(3.2-21.9)	(1.02-19.08)	(0.33-58)	(5.7-177)	(254-352)	(2.8-57.2)
Pagasitikos	9.23±1.47	7.36±5.45	5.54±6.88	519.5±344	2788±3157	26.10±21.22
N=23	(7.31-12.1)	(1.42-17.95)	(0.72-20.17)	(58-1014)	(56.5-9699)	(2.98-62.35)
Rodos	6.29±1.41	6.88±2.76	7.13±3.24	164.4±191.9	975±586	6.44±4.38
N=45	(4-10.4)	(1.76-13.98)	(1.59-22.33)	(47.8-631.7)	(158-2218)	(1.73-18.32)
Saronikos	10.42±3.47	6.51±6.31	17.83±10.35	56.9±15.3	710±351	8.23±4.69
N=146	(3.31-35.3)	(0.37-36.21)	(1.74-53.7)	(4.8-138)	(110-2103)	(1.69-27.03)
Santorini	3.69±1.3	1.01±0.7	5.34±3.12	34.9±15.3	223±70	4.07±2.67
N=4	(2-4.96)	(0.1-1.6)	(2.6-9.17)	(17-50)	(143-311)	(1.4-7.3)

Source: *CATSIKI et al., 2001a.*

(corresponding to 2.25 μg/g dry weight) for fish fillets. 55% of the cadmium measurements contain levels less than 0.05 μg/g dry weight, that are below the legal permissible concentration for Cd in common fish (0.05 μg/g fresh weight or 0.25 μg/g dry weight).

Lead was also scarcely measured in fish. Its values varied between 0.05 and 3.75 μg/g. The existing Hellenic and EU legislation permits the consumption of fish with Pb concentration less than 0.2 or 0.4 μg/g fresh weight (corresponding to 0,9 or 1,8 μg/g dry weight). Consequently, 25% of the samples exceeded the above concentrations. However, also in this case the analytical methodologies could account for this excess.

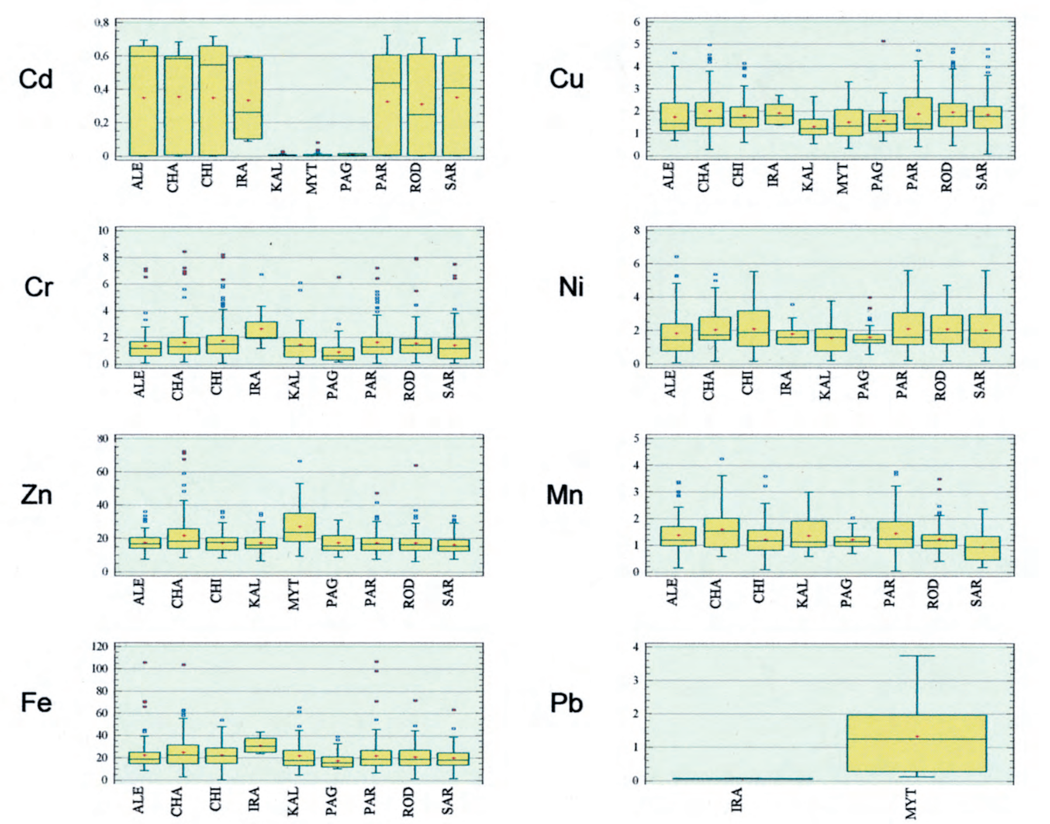
Copper and zinc maximum levels (5.14 μg/g dry weight or 1.14 μg/g fresh weight and 72.5 or 16.1 μg/g fresh weight) are below the permitted concentrations for food in Australia (10.00 and 150 μg/g fresh weight respectively). For the remaining metals nickel, chromium, iron and manganese very little information exists for relative legislation.

Bioaccumulation varied according to the fish sampling area (Figure IV.30). Samples from Kriti

Table IV.11: *Metal concentration in red mullets from Hellenic seas (in μg/g dry weight).*

	Hg	Cd	Cr	Cu	Ni	Zn	Fe	Mn	Pb
N	7	430	966	1035	992	963	974	547	45
Average	0.034	0.27	1.52	1.78	1.96	18.2	21.9	1.30	1.17
STD	0.005	0.30	1.31	0.84	1.22	7.86	11.7	0.67	1.11
Median	0.033	0.02	1.20	1.58	1.65	16.8	19.3	1.18	0.91

Source: *Hellenic MED-POL data (1993-2002).*



Source: *MED-POL, Aegean data set (HCMR).*

Note: ALE=Alexandroupolis; CHA= Chania (Kriti isl.); IRA=Irakleio (Kriti isl.); CHI=Chios isl.; KAL=Kalamata; MYT=Mytilini; PAG=Pagasitikos G.; SAR=Saronikos G.; PAR=Parga; ROD=Rodos isl.

Figure IV.30: *Box and Whiskers plots of metal concentration values in red mullets from Hellenic seas (in μg/g dry weight).*

Island (Chania and Irakleio) had generally the highest or higher values for most metals; while those from Lesvos Island and Kalamata, and in some cases Pagasitikos Gulf (Volos) had the lowest ones. Although the differences among areas are statistically significant, their value is more scientific than environmental. Moreover, the measured metal values seem to be lower or similar to previous ones. They are in agreement with results regarding other Mediterranean non-polluted areas (CATSIKI & STROGYLOUDI, 1999) and consequently, the consumption of these fish does not represent any danger to public health.

BIOTA IN THE SARONIKOS GULF

With the exceptions of the Elefsis Bay and some local areas near the industrial zone, the Saronikos Gulf's biota are generally moderately contaminated by metals. Among the studied metals mainly Ni seems to be abundant in marine life from the Saronikos Gulf. However, data are similar to those cited by the European Environment Agency for the Mediterranean (EEA, 1999).

The horizontal distribution of metals is assessed using about 1 300 mussel samples collected during the period 1985-1999 from four sampling stations (Figure IV.31). Results are presented in Table IV.12 and Figure IV.32.

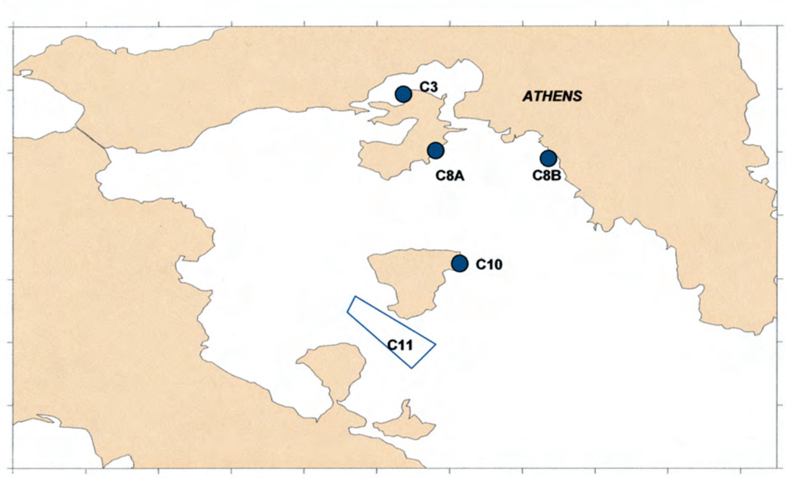
Statistical treatment of the results showed that metals generally decreased from the northern to the southern coasts of the Saronikos. Differences in metal bioaccumulation between samples collected at the four sampling sites were statistically significant ($P<0.001$). Agios Kosmas' samples present the highest levels of Zn, Cu, Fe, Cd and the lowest of Ni as opposed to Agia Marina in Aigina, which exhibits the lowest metal concentrations, with the exception of Cd. High level concentrations of Cd in Aigina have also been measured in sea water (Dasenakis, pers. Communication) which implies a possible local source.

The metallic temporal evolution in mussel samples present important fluctuations related to biological factors (i.e. the higher bioaccumulation

Table IV.12: *Concentration of metals in mussels from the Saronikos Gulf during 1985-1999 (in µg/g dry weight).*

	Cu	Cr	Cd	Ni	Zn	Fe	Mn	Pb
N	1209	1197	724	1206	1184	844	1063	145
Average	6.84	4.29	1.00	4.84	136	219	10.10	12.79
STD	3.04	3.07	0.64	3.24	76	178	7.50	4.10
Median	6.36	3.53	0.90	4.24	112	163	8.03	13.52

Source: *MED-POL Saronikos data set (HCMR).*



Note: sites code: C3=Faneromeni, Salamina, C8A= Kaki Vigla, C8B= Agios Kosmas, C10=Agia Marina, Aigina, C11=Fish collection between Aigina - Methana.

Figure IV.31: *Location of biota sampling stations in the Saronikos Gulf.*

during the cold periods of the year) and environmental ones, (i.e. the sea water quality). We noticed the simultaneous decrease or increase of metallic levels in the mussels from all the sampling stations suggesting that these fluctuations are related to environmental factors common to the whole of the Saronikos Gulf.

A specific statistical treatment of the data, such as the LWC (Locally Weighted Regression) smoothing technique (reducing the fluctuations) revealed that during the end of 1993 and the first months of 1994 Cu, Ni, Zn and Fe seemed to attain the lower levels of the period 1985-1999, while the opposite occurred for Cr.

Regression analysis ($P<0.05$) gave positive results in the case of Zn, Fe and Pb and negative ones for Cd and Ni. The first group of metals increases in the Saronikos Gulf during the covered period, the second decreases, while for Cu, Mn and Cr the observed fluctuations mask the overall trend (Figure IV.33).

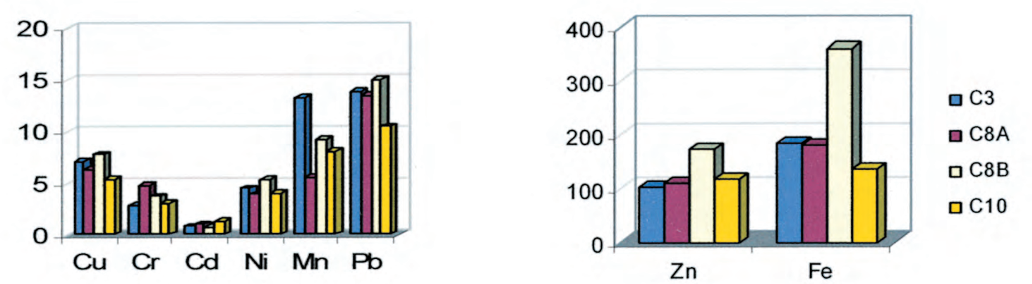
The observed increasing trend for Zn, Fe and locally for Cu (in stations C3 and C10) yield on robust data and should be taken into consideration by the decision makers since the actual sewage treatment only indirectly removes metals.

BIOTA IN THE THERMAIKOS GULF

Results from the previous paragraphs showed that the Thermaikos Gulf's biota seemed to be more contaminated by Hg and Mn than other Hellenic marine areas. However, data are similar to those cited by the Report of the European Environmental Agency for the Mediterranean (EEA, 1999).

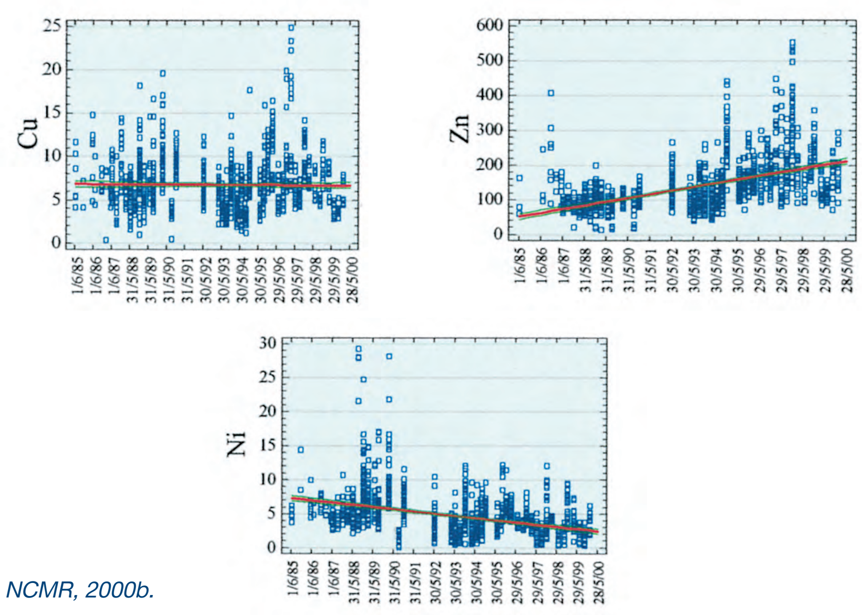
The horizontal distribution of metals in the

Figure IV.32: Median values of metals in mussels from four sampling sites in the Saronikos Gulf during the period 1985-1999.



Note: sites code: C3=Faneromeni, Salamina C8A= Kaki Vigla, C8B= Agios Kosmas, C10=Agia Marina, Aigina.

Figure IV.33: Regression analysis of bioaccumulation data from the Saronikos revealing the overall trends during the period 1985-1999.



Source: *NCMR, 2000b.*

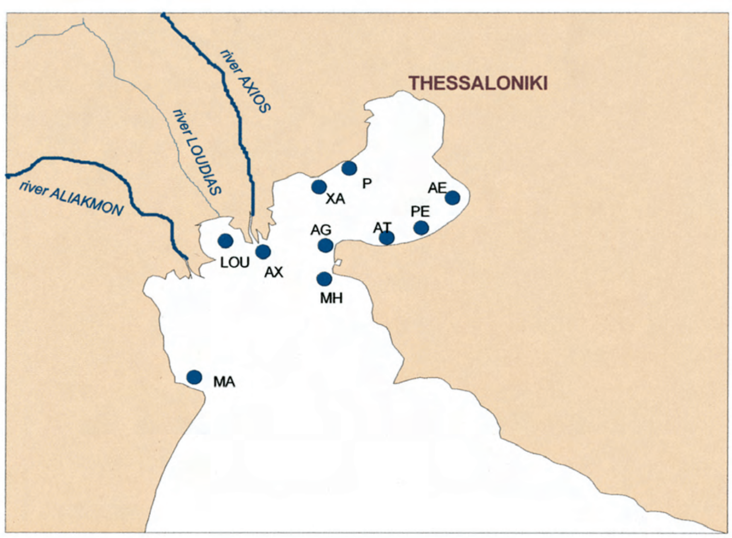
Thermaikos Gulf is assessed via mussels collected from ten coastal areas during the period 1999-2002 (Figure IV.34) coming both from natural and cultivated populations. Results are presented in Table IV.13 and Figure IV.35.

Statistical treatment of the results showed that

***Table IV.13:** Concentration of metals in mussels from the Thermaikos Gulf during 1999-2002 (in μg/g dry weight).*

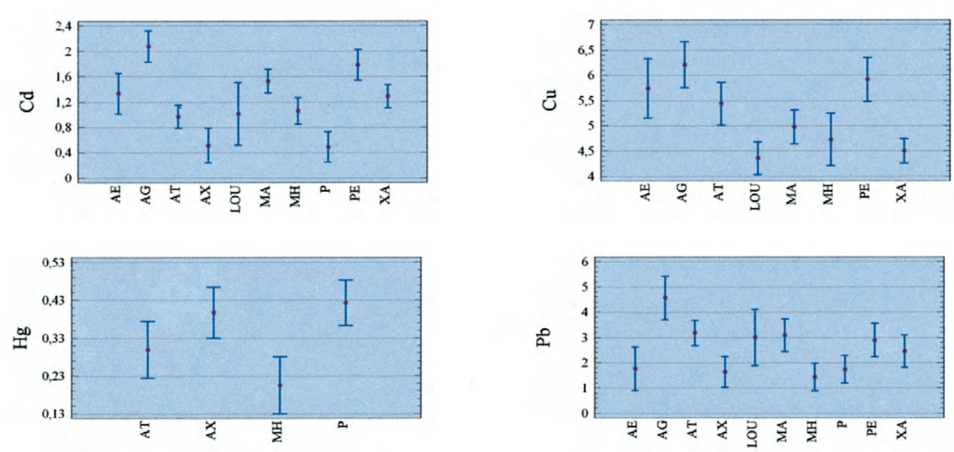
	Cd	Cu	Cr	Ni	Zn	Fe	Mn	Pb	Hg
N	288	225	225	225	222	186	217	187	79
Average	1.23	5.49	2.58	3.45	92.0	363.7	15.23	2.59	0.36
STD	0.96	1.76	1.40	1.83	43.2	285.1	9.04	2.20	0.25
Median	1.02	5.27	2.28	3.03	77.5	283.6	12.36	1.80	0.29

***Source:** HCMR, 2003a. CATSIKI et al., 2005.*



Note: Site codes: XA= Chalastra, P=Paleomana, AT=Agia Triada, AE=Airport, AG =Angelohori, PE=Peraia, MA=Makrigialos, MH=Michaniona, LOU=Loudias, AX= Axios.

Figure IV.34:
Mussel sampling stations in the Thermaikos Gulf.



***Source:** CATSIKI et al., 2005.*

Note. Site codes: XA= Chalastra, P=Paleomana, AT=Agia Triada, AE=Airport, AG =Angelohori, PE=Peraia, MA=Makrigialos, MH=Michaniona, LOU=Loudias, AX= Axios.

Figure IV.35:
Average and configuration intervals of metals bioaccumulation in mussels from the Thermaikos Gulf.

metals generally increase towards both sides of the Thermaikos Gulf. Differences in metal bioaccumulation between samples collected at the ten sampling stations were statistically significant ($P<0.001$). Station AG situated at the southeast coast of the Thermaikos (Angelohori) presented the highest metallic levels (except Ni), while station PE (Peraia) also located on the east coast had very elevated levels of Cd and Cu. On the other side of the gulf, station MA (Makrigialos) exhibited the highest levels of Cd, Cr, Ni, Mn, Pb and LOU Station (Loudias) had also very elevated levels of Ni, Mn and Pb; phenomenon probably due to the impact of the rivers estuaries and the existence of a dump in the Axios delta area (NCMR, 2000c). The presence of Cd is particularly believed to be equally due to pollution load from former. Yugoslavia and the extinction of agricultural areas, since it constitutes an important admixture of fertilisers (NCMR, 2000c).

CONCLUSIONS

Metal bioaccumulation in Hellenic biota (mussels, limpets and red mullets) collected during the period 1990-2002 from several coastal areas and gulfs can be considered as low and similar to that from other non-polluted Mediterranean areas. Exceptions concern areas subjected to heavy anthropogenic activities, today, or in the past such as Lavrio, Larymna bay, etc.

The studied areas present different metal characteristics due to background levels, or anthropogenic activities, or both. Among them, the Saronikos Gulf seems to be more contaminated by Zn, Pb, Ni and to a lesser degree by Cu, Cr; the Thermaikos Gulf by Hg and Mn; the Pagasitikos Gulf by Zn and Mn and to a lesser degree by Pb, Cu, Cr, Fe; and Larymna bay by Ni, Fe, Cr. In addition, most metals were elevated in fish from Kriti Island. We must, however, notice that the relevant data were produced by different Hellenic laboratories and consequently differences between areas should not be overestimated. However, in the Saronikos Gulf, over the period 1985-1999, an increasing trend in metal bioaccumulation by mussels was observed for Zn, Fe and Pb as opposed to a decreasing one for Cd and Ni; a fact that should be taken into consideration.

IV.4. ORGANOCHLORINE COMPOUNDS

INTRODUCTION

Polychlorinated Biphenyls (PCBs), along with chlorinated pesticides are by far the most important group of the persistent organic pollutants (POPs), as they are characterised by high resistance to photolytic, biological or chemical degradation. There are 209 chlorinated biphenyl congeners with different substitutions on the biphenyl groups of which about 150 are used in technical products. The number and positioning of the chlorines influences both toxicity and physical properties such as solubility and vapour pressure.

PCBs are a class of highly toxic, persistent and bioaccumulative compounds that were introduced in 1929 and manufactured in the United States, Japan and most European countries. They are chemically stable and heat-resistant, and were used worldwide as transformer and capacitor oils, hydraulic and heat-exchange fluids, lubrica-ting and cutting oils, and as plasticiser in joint sealants (Figure IV.36).

By the late 1970s, evidence of the extreme persistence and adverse health effects of PCBs had resulted in bans on their manufacture in most countries. Many industrialised countries have now taken steps to control and restrict the flow of PCBs into the environment. The most influential force leading to these restrictions has probably been a 1973 recommendation from the Organisation for Economic Cooperation and Development (OECD), (WHO, 1993). Although they are no longer manufactured or imported into many countries, there remain sizeable quantities in storage. In addition, PCB fluids are present in many older transformers, fluorescent lighting fixtures and other electrical devices and appliances. These are vulnerable to release into the environment, as older components can leach. Other sources of PCB contamination come from improper disposal or incineration of PCBs and PCB-containing waste sites.

A problem when comparing and interpreting PCB data is that different scientists measure and report

Source: *UNEP Chemicals, 1999.*

Figure IV.36:
Materials containing PCBs.

varying numbers of PCB congeners. The reported sum of PCBs can correspond to as little as seven or as many as 60 congeners or even to technical mixtures equivalents such as arochlors. In this chapter the term PCBs in most cases refers to the sum of the following eleven congeners: CB101, CB105, CB118, CB 128, CM138, CB153, CB156, CB170, CB180, CB183 and CB194.

DDT is the most known and widespread chlorinated organic pesticide (Figure IV.37). It was introduced as an insecticide in 1945 and since then it has been used in large amounts to control disease-carrying insects and especially mosquitoes. It is estimated that during 1948 - 1993 the global production and usage of DDT exceeded 1 500 000 tonnes. After environmental impairments caused by the extensive use of DDT were manifested, some legislative restrictions were imposed and in 1972 DDT was banned in North America and in many countries in western Europe, including Hellas. It is still used in other parts of the world, especially in tropical climates, areas from which it is subject to long-range transport.

DDT is readily metabolised in the environment into DDE, which is a stable and equally toxic compound, and DDD. DDE is the main metabolite whereas DDD production is favoured under anoxic conditions. The analytical results are usually expressed as total DDTs, which is the sum of the parent compound and its metabolites.

Hexachlorobenzene (HCB) is an industrial product, which was used as insecticide and fungicide. It is also characterised by high toxicity, stability and bioaccumulative capability and was banned in Hellas in 1974.

Hexacholohexanes (HCHs) are a mixture of isomers including α-HCH, β-HCH and γ-HCH. γ-HCH, known as lindane, is a very strong insecticide and utilised in various agricultural activities. Lindane is more biodegradable than the other organochlorine compound and its use in Hellas is still permitted.

INPUTS IN THE MARINE ENVIRONMENT

The most important source of organochlorine compounds, in both the coastal environment and in the open marine ecosystem, appears to be atmospheric deposition occurring either as wet or dry deposition or as vapour phase absorption. PCBs emitted and deposited during the years of intensive production and use are still a diffuse source to the global environment. Evaporation of PCBs from polluted soils and waters is a significant source into the atmosphere. Once in the atmosphere, PCBs enter the global circulation and can travel long distances either as molecules in the gas phase or absorbed in particles and suspended in aerosols.

As a result of PCB banning since the 1970s, riverine inputs of PCBs or direct inputs from industrial and municipal outfalls, wastewaters or sewage sludge are low compared with aerial inputs but they can be locally damaging. It is estimated that for PCBs 80% and for DDTs 98% of the total inputs are the atmospheric ones (CLARK, 1997).

For Hellas no real data on organochlorines emissions or inputs exist. According to EMEP and

Figure IV.37: *DDT Bottle.*

Source: *http://www.tinshop.co.uk/pics/549a.jpg.*

based on modeling results the PCB emission rate in 1998 was estimated at 0.2 tonnes/year (EMEP, 2003) (Figure IV.38).

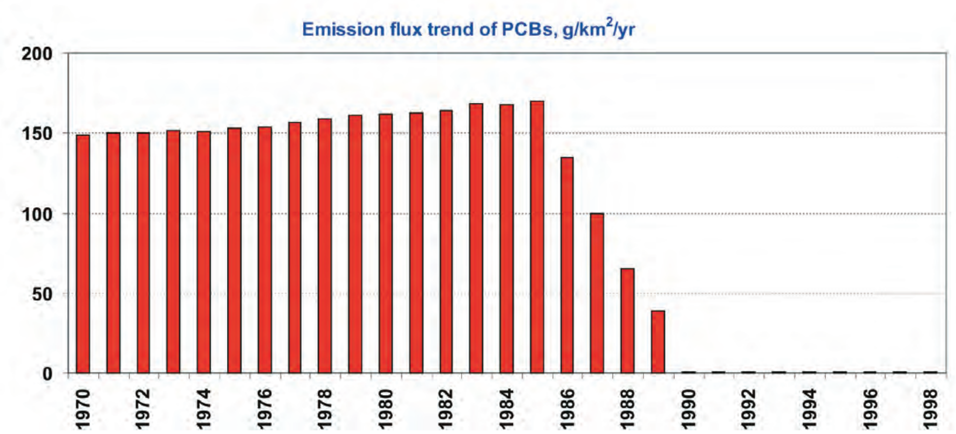
CONCENTRATIONS IN SEA WATER

Organochlorines are highly hydrophobic compounds with negligible water solubility and, therefore, their concentration in sea water is usually extremely low and this makes a reliable quantification difficult. In most cases the compounds found in the water column are associated with particulate matter, whereas their dissolved forms which are the result of association to dissolved or colloidal organic matter are reported to be in the low pg/L range.

In Hellas organochlorine distribution in sea water has not been extensively studied as it is shown in Table IV.14. DDTs were measured in the coastal zone of the Thermaikos Gulf during 1993 – 1998 and their values ranged between 0.1 and 13.9 ng/L (mean value 2.05 ng/L). Similar studies performed in the Strymonikos Gulf and the Bay of Kavala clearly showed lower DDTs concentrations, while in a study in the outer Thermaikos Gulf conducted during 2000 – 2001, DDTs concentrations in unfiltered sea water were found to be very low (< 0.02 ng/L). PCBs concentrations (expressed as the sum of 11 congeners) were also measured in this study and found to be always below 0.05 ng/L (mean value 0.02 ng/L). In Elefsis Bay, an area

Table IV.14: *PCBs and DDTs concentrations in sea water collected from various Hellenic marine areas. PCBs correspond to the sum of CB101, CB105, CB118, CB 128, CM138, CB153, CB156, CB170, CB180, CB183 & CB194. DDTs correspond to the sum of p,p'-DDT, p,p'-DDD, p,p'-DDE.*

	PCBs (ng/L)	DDTs (ng/L)	Year of survey	Source
Thermaikos Gulf coastal zone		2.1 ± 4.2 (0.1 – 13.9)	1993 - 1998	MEDPOL data
Strymonikos Gulf		0.5 ± 2.1 (0.1 – 4.1)	1993 - 1998	MEDPOL data
Kavala Bay		0.7 ± 1.1 (0.1 – 4.7)	1993 - 1998	MEDPOL data
Outer Thermaikos Gulf	< 0.05	< 0.02	2000 - 2001	HCMR, 2003a,b
Elefsis Bay	3-4 (filtered water) 4-5 (SPM)		1992	PANAGIOTOPOULOU *et al,* 1996
Elefsis Bay	0.7 – 2.0		2002	HCMR, 2003c



Source: *EMEP, 2003.*

Figure IV.38: *Trends in PCB emission fluxes in Hellas, 1970 – 1998 (averaged over the country).*

strongly influenced by industrial effluents, PCBs concentrations in sea water had been measured in 1992 and found in the range of 3-4 ng/L in filtered sea water and 4-5 ng/L in SPM. In 2002 measurements in the same area resulted in clearly lower concentrations ranging between 0.7 and 2.0 ng/L in unfiltered samples, probably reflecting the declining use and progressive elimination of PCBs.

HCB and lindane measurements have been reported for the coastal zone in the Strymonikos and Thermaikos gulfs and in Kavala Bay. Their concentrations were low in all cases and ranged from 0.1 to 14.0 ng/L for HCB and from 0.1 to 18.4 ng/L for lindane.

CONCENTRATIONS IN SEDIMENTS

Marine sediments and especially the fine-textured ones are considered as the main repositories of organochlorines in the marine environment. Organochlorine compounds concentrations in sediments depend, not only on the distance from point sources, but also tend to be closely correlated with organic carbon. In Hellenic marine areas measurements performed so far revealed low levels of contamination from organochlorine compounds. The existing data on organochlorine concentrations are summarised in Table IV.15. In the Strymonas River estuaries in the north Aegean Sea PCBs concentrations in total sediment ranged from 0.1 to 3.0 ng/g and a gradient was observed towards the mouth of the river (HATZIANESTIS & SKLIVAGOU, 2001). In the Nestos delta PCBs concentrations were even lower (0.1 – 1.8 ng/g) while similar values were found along the northern coast of Greece (HATZIANESTIS & SKLIVAGOU, 2000). In surface sediments collected from the coastal zone in Rodos Island PCBs concentrations were also very low. In the outer Thermaikos negligible contamination from PCBs was found (0.1 – 1.5 ng/g), but in the inner gulf and especially in the vicinity of the city of Thessaloniki significantly higher values were recorded (1.7 – 24.5 ng/g), indicating low to moderate contamination (HATZIANESTIS *et al.*, 2001a). In Elefsis Bay, which is considered as the most contaminated marine area in Hellas, PCBs were measured in 1992 and their concentrations were found to be relatively high (55 ng/g). In 2000, PCB distribution was studied in sediment cores

Table IV.15: *PCBs and DDTs concentrations in surface sediments collected from various Hellenic marine areas. PCBs correspond to the sum of CB101, CB105, CB118, CB 128, CM138, CB153, CB156, CB170, CB180, CB183 & CB194. DDTs correspond to the sum of p,p'-DDT, p,p'-DDD, p,p'-DDE.*

	PCBs (ng/g dw) (mean)	DDTs (ng/g dw) (mean)	Year of survey	Source
Outer Thermaikos Gulf	0.5 ± 0.6 (0.1 – 1.5)	1.3 ± 2.1 (0.2 – 5.8)	2000 - 2001	HCMR, 2003a
Gulf of Thessaloniki	5.0 ± 7.4 (1.7 – 24.5)	3.8 ± 3.2 (1.5 – 11.8)	1995 - 2001	HATZIANESTIS *et al.*, 2001a
Strymonikos Gulf	1.1 ± 0.7 (0.1 – 3.0)	11.0 ± 8.9 (0.6 – 48.1)	1998	HATZIANESTIS & SKLIVAGOU, 2001
Nestos Delta	0.6 ± 0.6 (0.1 – 1.8)	4.5 ± 3.7 (0.2 – 16.7)	1998	HATZIANESTIS & SKLIVAGOU, 2000
Gulf of Igoumenitsa	0.5 ± 0.3 (0.2 – 1.0)	1.5 ± 2.6 (0.3 – 8.2)	2000	LELEKIS *et al.*, 2001
Kalamas estuaries	1.1 ± 1.2 (0.1 – 3.2)	0.3 ± 0.7 (0.2 – 1.2)	2000	LELEKIS *et al*, 2001
Coastal areas in Rodos	0.8 ± 0.3 (0.3 – 1.3)	0.2 ± 0.1 (0.2 – 0.4)	2003	HCMR, 2004
Elefsis Bay	29.2 ± 11.6 (8.1 – 55.1)	4.1 ± 2.5 (0.4 – 8.5)	1992, 2000	PANAGIOTOPOULOU *et al.*, 1996
Peiraias Port	68.9 ± 5.7 (62.7 – 78.9)	54.8 ± 4.8 (46.6 – 62.1)	1996	NCMR, 1996b
Thessaloniki Port	88.5	22.8	1996	HATZIANESTIS *et al.*, 2001a

collected from the same area. In this study surface PCB concentrations were clearly lower than those in 1992 and ranged between 8.1 and 23.4 ng/g, but significantly higher values were found at the deeper parts of the cores. The maximum concentration was 160.9 ng/g and was measured at the 5-6 cm section of the core. These findings confirm the decreased inputs of PCBs during the last years, as a result of the restrictions imposed. The highest PCB concentrations in Hellas were measured in surface sediments collected from the port of Peiraias (62-80 ng/g) and the port of Thessaloniki (88 ng/g).

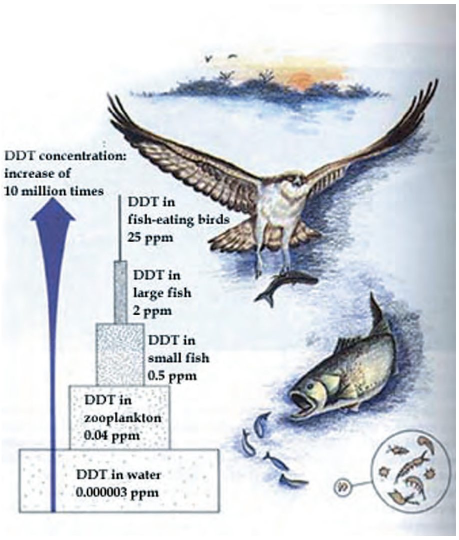
In all the sediment samples the congener distribution was similar, with CB153 presenting the higher values, followed by CB138, CB118 and CB180. This is in accordance with the composition of the commercial technical mixtures used.

DDTs concentrations in marine sediments are generally within the same order of magnitude as those of PCBs (Table IV.15). Lower values than those of PCBs were found in areas receiving urban and industrial effluents (Elefsis Bay, Thermaikos Gulf, ports of Peiraias and Thessaloniki), whereas higher concentrations were recorded in areas influenced by agricultural activities.

The main metabolite of DDT, DDE was in most cases the most abundant compound of DDTs mixtures, but in the Thermaikos Gulf sediments, DDT was also measured in relatively high percentages and this might indicate some recent inputs of DDT in the area, despite the restrictions in its use.

CONCENTRATIONS IN MARINE ORGANISMS

As a consequence of their hydrophobic and persistent character, organochlorine compounds are easily bioaccumulated and their highest concentrations are usually found in marine biota (Figure IV.39). Mussels, as filter feeding organisms, may accumulate significant quantities of organochlorine compounds through consumption of contaminated food particles, sediments and water. Fish may accumulate organochlorine compounds through at least two distinct routes: a) by absorption through the gill membranes following absorption of material from water onto the gill surface b) by consumption of contaminated food. Which of these mechanisms is the most important will depend on many variables, such as the level of contamination of foodstuffs, the feeding habits of the particular species and the lipid content of the tissues. In the framework of the Hellenic monitoring programmes organochlorine compound concentrations are determined in mussels and in commercial fish species (red mullets and bogues) collected from various marine areas in the Aegean and Ionian seas In all cases organochlorine



Source: *http://pacific.fws.gov*

Figure IV.39:
Biomagnification of DDT through the food web.

concentrations are quite low and significantly lower than those considered as dangerous for human consumption.

In mussels *(Mytilus galoprovincialis)* collected from three marine areas in Hellas (HATZIANESTIS *et al.*, 2000, 2001b, 2002, CATSIKI *et al.*, 2001b) the highest PCB values (the sum of 11 congeners) were measured in the Saronikos Gulf, which is influenced by the industrial zone around Athens (ΣPCBs range 8.9 – 229 ng/g dw mean value 52.9 ± 31.4 ng/g dw). In the other two regions where measurements have been performed, PCBs concentrations were low (Amvrakikos: ΣPCBs range 3.0 - 31.5 ng/g dw, mean value 10.4 ± 11.2 ng/g dw, Thermaikos: ΣPCBs range 2.0 – 26.3 ng/g dw, mean value 10.0 ± 7.7 ng/g).

The highest concentrations for the DDT compounds were found in mussels collected from the Amvrakikos Gulf (ΣDDTs range 19.4-287.7 ng/g, mean value 81.0 ± 45.8 ng/g), which according to these data seems to be moderately contaminated. This pollution is probably attributed to the intense agricultural activities in the area. In the Saronikos and Thermaikos gulfs similar values were recorded, which were significantly lower than those in the Amvrakikos (Saronikos: ΣDDTs range 3.4-200.8 ng/g, mean value 22.7 ± 34.7 ng/g, Thermaikos: ΣDDTs range 6.2-84.0 ng/g, mean value 23.2 ± 21.9 ng/g). DDE was always the predominant component comprising 41.7 – 92.3 % of the total DDTs. Relatively high concentrations of DDT were measured only in the Thermaikos Gulf mussels, in agreement with sediment measurements and confirms probable recent inputs of DDT in theThermaikos Gulf.

A long term study of PCBs and DDTs temporal trends in mussels was conducted only for the Saronikos Gulf and includes the years 1988 – 2001 (Figure IV.40). Despite the declining use and

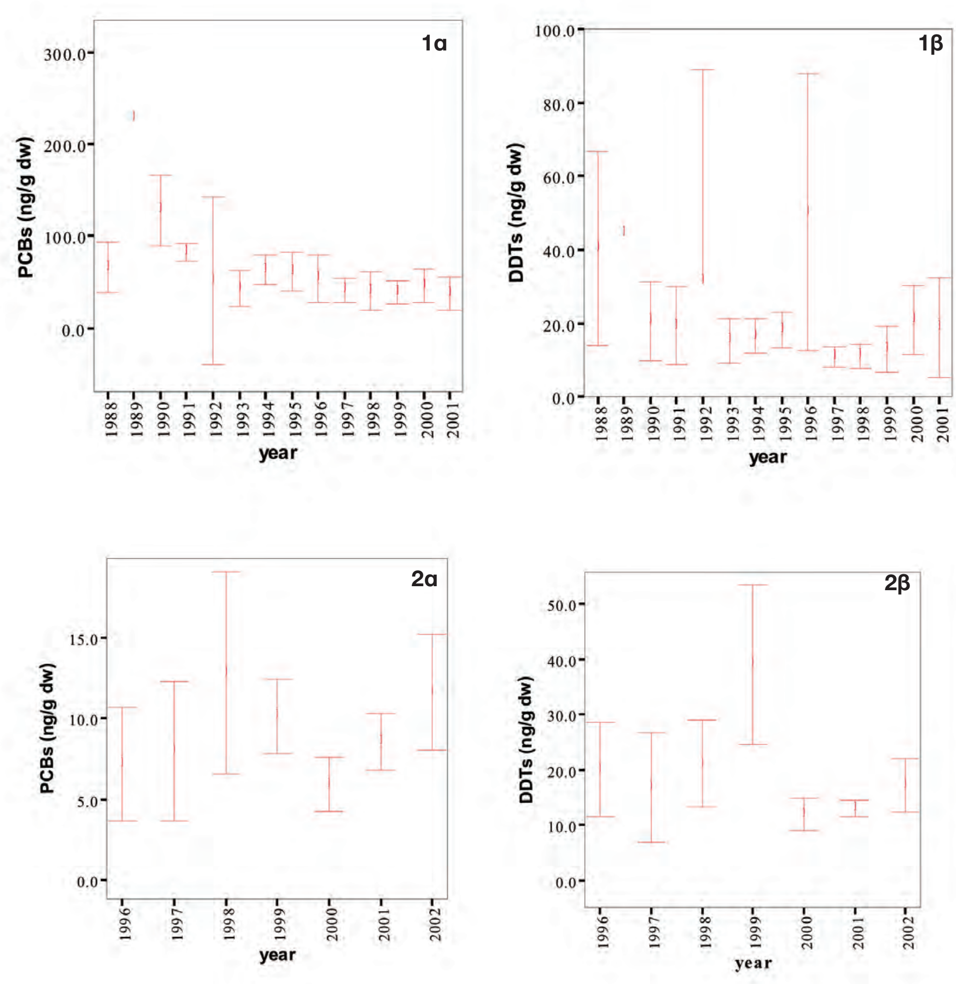


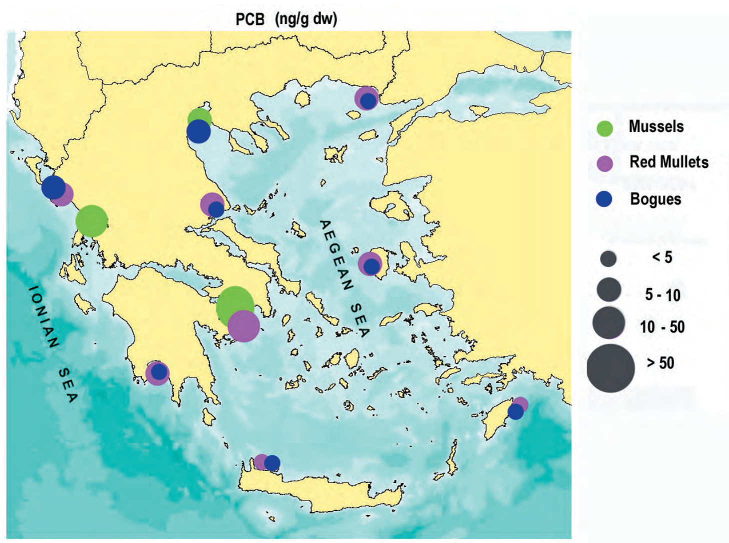
Figure IV.40: *Temporal trends of PCBs and DDTs concentrations in mussels Mytilus galloprovincialis collected from the Saronikos Gulf during 1988 – 2001 and collected from the Thermaikos Gulf during 1996 – 2002 (1a) PCBs in the Saronikos Gulf (1b) DDTs in the Saronikos Gulf (2a) PCBs in the Thermaikos Gulf (2b) DDTs in the Thermaikos Gulf.*

Source: *HCMR, MED-POL Reports.*

progressive elimination of PCBs, no clear decreasing trend was observed during these years. This stability of PCB concentrations over the years could not be explained only by the high persistence of these compounds and probably indicates that there are still continuous inputs into the coastal environment either by atmospheric deposition, which is considered as the most important recycling route, or by direct discharges. However, although the results of PCB analysis after 1988 are not directly comparable with previous measurements due to different analytical and calculation practices, it seems that a decline occurred during the 1970s and early 1980s. DDTs concentrations in mussels appear also relatively constant after 1990 while some unexpectedly high values were measured during 1996.

For the Thermaikos Gulf the results of PCBs and DDTs analyses in mussel samples during 1996 – 2002 demonstrated high variability and unclear temporal trends (Figure IV.40 2a. 2b). The highest DDTs values were determined in 1999.

The concentrations for PCBs and DDTs in fish and mussels are presented in Figure IV.41 (GEORGAKOPOULOS *et al.*, 1991, GIOURANOVITS *et al.*, 1994, HATZIANESTIS *et al.*, 2001b). In all cases the concentrations were quite low and never exceeded human health limits (ROACH & RUNCIE, 1998). The highest values of DDTs and PCBs were found in red mullet (mean DDTs values: 12.4 ng/g in red mullets and 3.0 ng/g in bogues, mean PCBs values: 8.0 ng/g in red mullets and 3.5 in bogues). These statistically significant differences can be attributed to a) the higher lipid content of red mullets (1.5% in bogues, 3.3% in red mullets) and b) the



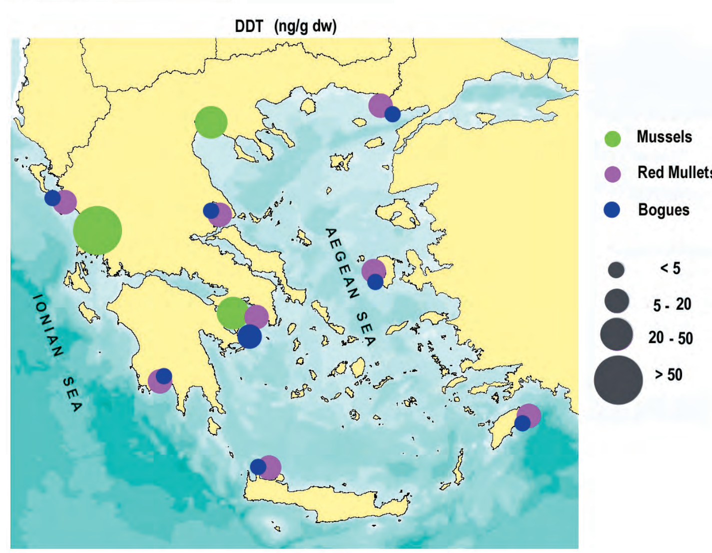


Figure IV.41: *PCBs and DDTs concentrations in mussels (ng/g dw) and fishes (ng/g ww) collected from various Hellenic marine areas.*

Source: *HCMR, MEDPOL Reports.*

Note: PCBs correspond to the sum of CB101, CB105, CB118, CB 128, CM138, CB153, CB156, CB179, CB180 & CB194. DDTs correspond to the sum of p,p'-DDT, p,p'-DDD, p,p'-DDE.

different feeding conditions of the two species. Normalisation of the results to the fat content demonstrated that, while DDTs continue to be significantly higher in red mullets (mean values 457 ng/g fat in red mullets and 232 ng/g fat in bogues), equal PCBs values occur in the two fish species (means: 248 ng/g fat and 272 ng/g fat). This preferential bioconcentration of DDTs in red mullet, which needs further investigation, might be related to the different dietary intake of these sea bottom feeders.

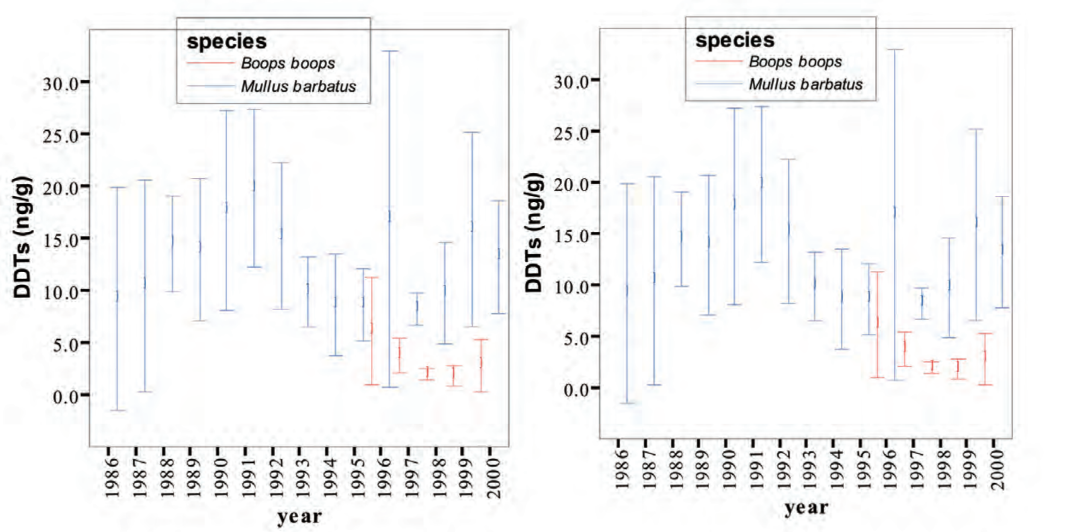
The spatial distribution of DDTs and PCBs in fish tissues from the Aegean and Ionian seas is generally homogeneous for both fish species, evidencing that no particular point sources are responsible for the current level of contamination, in accordance with the banning of these compounds since the 1970s. PCBs only exhibited higher values in fishes from the Saronikos Gulf, whereas slightly lower values were found in Chania and Rodos.

Examination of temporal trends for a period of 14 years (1986 – 2001) reveals that for both species no significant differences in organochlorine contamination levels existed during this time period (Figure IV.42).

Except the edible fish species, organochlorine concentrations were also reported in tissues of a common Mediterranean cetacean species the Cuvier's Beaked whale *(Ziphius cavirostris)* (HATZIANESTIS *et al.*, 1998). The samples were collected from ten specimens stranded on a sandy beach of the Kyparissiakos Gulf in the south Ionian Sea, in May 1996. Organochlorine residues were found to be about 3 orders of magnitude higher than those in fish tissues and ranged from 11.2 to 35.1 μg/g wet wt (mean 20.9 μg/g wet wt) for DDTs and between 3.0 and 12.1 μg/g wet wt (mean 7.5 μg/g wet wt) for PCBs. These high values are indicative of an important biomagnification through the marine food web.

CONCLUSIONS

Organochlorine compound levels in the Hellenic marine environment are generally low. The most contaminated areas are the coastal zones around the cities of Peiraias and Thessaloniki and Elefsis bay. Riverine inputs also appear to be limited, as very low concentrations for both PCBs and DDTs were detected in the most important estuaries. In marine biota systematic measurements have been performed in mussels and two common fish species. In all cases organochlorine values detected were well below those considered dangerous for human consumers. The highest contamination for PCBs was observed in mussels collected from the Saronikos Gulf and for DDTs in mussels collected from the Amvrakikos Gulf. Examination of temporal trends for a period of 14 years (1988 – 2001) revealed that no significant differences in organochlorine contamination levels in fishes from Hellenic waters existed during this time period, despite the banning of these compounds since the 1970s.



Source: *HCMR, MEDPOL Reports.*

Figure IV.42: *Temporal trends of PCBs and DDTs concentrations in fishes Mullus barbatus and Boops boops collected from various areas of the Aegean and Ionian seas during 1986 – 2002.*

IV. GAPS IN KNOWLEDGE - FUTURE PERSPECTIVES

It becomes obvious from the previous chapters that there are still many gaps in knowledge regarding the water quality of the coastal zone; this includes the water column characteristics, the sediments but also levels of hazardous substances in some marine organisms. There are a number of projects monitoring the quality of the marine ecosystems with emphasis mainly on areas with increased anthropogenic activities such as the Thermaikos Gulf, the Saronikos Gulf, Elefsis Bay, etc. However, there is a lack of background information for most of the coastal areas and islands. For the sustainable management of the coastal zone, it is very useful to have data on the environmental state of as many coastal areas as possible; this means that the monitoring studies should be extended to identify more hot-spot areas but also to study the non-polluted areas.

Furthermore, most of the existing projects are related to the nutrient levels, some of the heavy metals and quite a limited number of organic hazardous substances. Without rejecting the importance of these studies, some compounds should be added. For example, the determination of more toxic metals like Hg and As and research on their bioavailability, should be included. Moreover, there is a need to monitor more systematically the levels of the highly persistent organochlorine compounds, especially in coastal areas influenced by anthropogenic activities. Regarding the marine biota, there are satisfactory time-series for mussels and two fish species; however, as the bioaccumulative capacity of these compounds is very high, other edible fish species belonging to higher trophic levels should also be studied.

The climatic changes in the Mediterranean region play also a critical role on the water column characteristics. The Eastern Mediterranean Transient had a strong influence on the oxygen and nutrient fields in all major water masses of the area. It is suitable to evaluate the impact of the nutrient redistribution on biological activity and to investigate the future role of the Adriatic and Aegean Sea on the deep-water formation processes. The peculiarities of the nutrients' ratios in the Mediterranean, their increase from the western to eastern Mediterranean and the extent of the dissolved organic nitrogen and phosphorus (DON and DOP) contribution in the nutrient budgets, need further investigation.

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CHAPTER V
BIOTA IN
WATER COLUMN

V. BIOTA IN WATER COLUMN

INTRODUCTION

Organisms are not distributed evenly throughout all parts of the seas. Life is most heavily concentrated in the coastal (nearshore) zones. Furthermore, every organism is limited to the area that it can inhabit. This results in a zonation of organisms, with certain species occupying certain zones. This is due to both physical and biological factors. The zonation and some relative terminology used in the texts that follow are given in Figure V.1.

The biology section (Chapters V and VI examine separately the pelagic (microbial, phytoplankton, zooplankton) and the benthic ecosystems/communities but both as a whole are examined in the lagoonal ecosystems. More details about the benthic communities (phyto zoobenthos) are provided in Chapters VI.3-5.

Diversity of planktonic ecosystems are described separately for coastal and deep waters. In contrast, the benthic ecosystem is examined as a whole, though differences within the benthic communities are discussed. The reason is that most studies deal with the infralittoral zone in semi-polluted or polluted areas, such as the Thermaikos and Saronikos gulfs as there are few reports from undisturbed areas and the midlittoral (for zoobenthos), lower infralittoral for phytobenthos. Also data on temporal trends, life cycles, trophic relations and productivity are scarce. The biodiversity of the hard bottom fauna of Hellenic Seas has received little attention, despite its cultural and economic importance.

Vocabulary widely used

Zonation - describes the different zones or areas of the marine environment.

Distribution - describes where animals live within these zones as well as their geographic distribution.

Benthic - extends from the Littoral, to the continental shelf, to the continental slope, to the bathyal and abyssal zones.

Coastal (or neritic) - the nearshore ocean environment, that which occurs above the continental shelf.

Pelagic - all of the ocean beyond the continental shelf, which is by far the most extensive.

Littoral - includes the supratidal zone (or spray zone), intertidal zone, which occurs between the highest and lowest tides in an area, and the subtidal zone, which is always covered by sea water, and extends into the neritic zone.

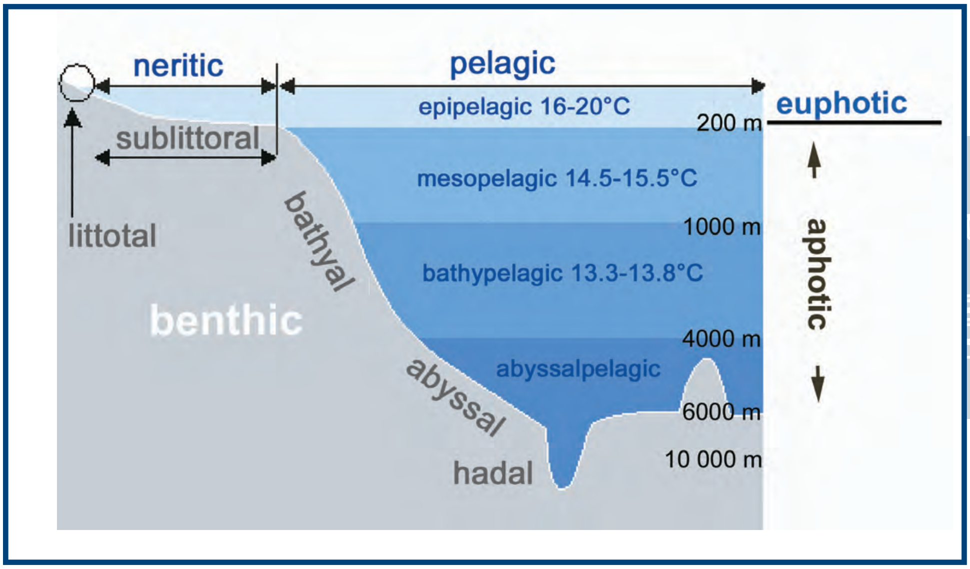


Figure V.1: *Zonation of pelagic and benthic ecosystems.*

V.1. MICROBES AND THE MICROBIAL FOOD WEB

The Role of the Infinitely SMALL is Infinitely LARGE

The term **'microbe'** includes all unicellular micro-organisms that are among the most numerous and most important inhabitants of marine environments. Microbes form an integral part of the marine ecosystem and are represented by autotrophic-heterorophic procaryotes (cyanobacteria, bacteria) and eucaryotes (algae, protozoa) as well as viruses (Figure V.2). These organisms are fundamental blocks of the ecosystem and their activities have a very significant influence on the various chemical and biological processes in the natural environment.

Until 1995 the available information from Hellenic waters was practically non-existent. During the last five years there has been a considerable increase in our knowledge on microbial processes through field and experimental work. Microbial studies in the Hellenic Seas comprise a 'descriptive' as well as a 'dynamic' aspect and research focus to answer some basic questions concerning:

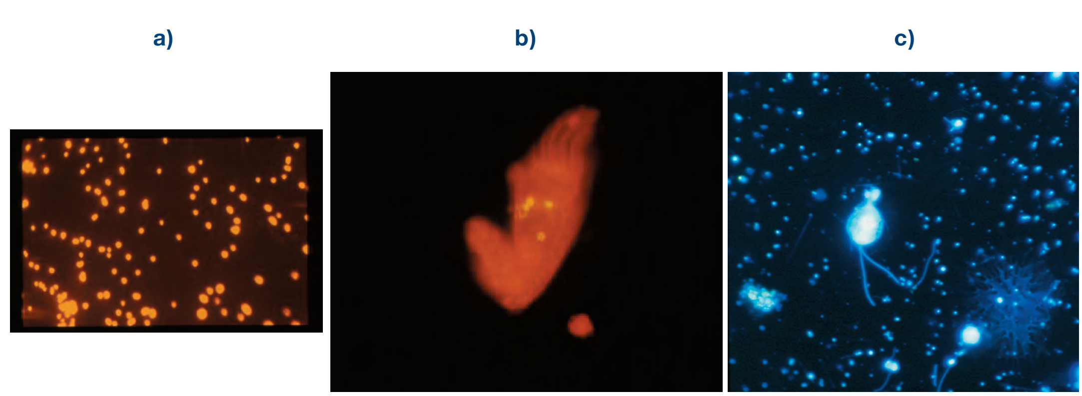
(1) microbial biomass and production dynamics;
(2) the control mechanisms of biomass (i.e the role of grazing vs. resource limitation);
(3) the role of micro-organisms in flux of matter and the flow of energy towards higher trophic levels in the marine food web.

By exploring relationships between microbes and their physical and biological surroundings, we aim at better defining the structure and function of the marine microbial food web in the coastal and open sea.

HETEROTROPHIC BACTERIA

Bacterioplankton are the most widely distributed organisms, reaching densities of over one million cells per ml (Table V.1). Bacterial abundance and production in the upper 100 m in the open Hellenic Seas are typical of oligotrophic conditions, with incorporation rates for ^{3}H-leucine indicating carbon production rates of 0.1-1.2 μg C l^{-1} d^{-1}. Average bacterial abundance offshore is around 0.5 x 10^6 cells ml^{-1}. Bacterial production in coastal areas was found up to four times greater than in the open sea. Bacterial abundance is also higher and more variable at near shore stations ranging up to 6.8 x 10^6 cells ml^{-1}.

Planktonic bacterial production in the open sea is related to primary production and the abundance of bacteria increases following phytoplankton blooms, indicating that bacteria are sustained by the flow of organic material from primary producers. The close coupling of bacterial and primary production is also indicative of the oligotrophic status of the open Hellenic Seas. One characteristic feature of the open Aegean Sea is the dominance of bacterial biomass over autotrophic biomass (Figure V.3), expressed with an increasing trend along the gradient of oligotrophy from the north to the south Aegean. During cruises of the EU MATER programme, long dissolved organic carbon (DOC)



Photos: *A. GIANNAKOUROU.*

Figure V.2: *Some representatives of the microbial food web: a. cyanobacteria, b. a mixotrophic ciliate fed with cyanobacteria, c. bacteria and heterotrophic flagellates.*

turnover times (30 to 60 days) and low bacterial production rates were recorded (mean 30 ng C l^{-1} h^{-1}), suggesting that a large percentage of bacteria present in the water column are not actively growing. Moreover, the extracellular enzyme activity and the uptake rates of monomers (amino acids) were low, supporting the hypothesis that they are energy-limited bacteria (Van WAMBEKE *et al.*, 2002). Phosphorus seems, to be the most important limiting factor; in a series of enrichment experiments the bottles that received P showed an increase of bacterial production up to 700% in 48 hours.

In coastal and more eutrophic areas a ratio Bacterial biomass/Phytoplankton biomass (BB/PB) of 0.2 is usually found. In the Thermaikos Gulf BB/PB range from 0.2 to >1 with increasing values from the coast to the outer area of the shelf, as well as during summer stratification (GIANNAKOUROU *et al.*, 2000). In some coastal waters near populated areas or river discharges such as the Thessaloniki Bay, the higher than expected values of bacterial biomass are related to allochthonous inputs of organic and inorganic nutrients and thus the availability of organic matter for bacteria growth is independent of phytoplankton.

Table V.1: *Values of microbial food web parameters in the open and coastal Hellenic aquatic systems. BA: bacterial abundance, BP: bacterial production, CYANO: cyanobacteria, PROCHLO: prochlorophytes, PNF: autotrophic nanoflagellates, HNF: heterotrophic nanoflagellates, CIL: ciliates.*

		BA X 10^6 ml^{-1}	BP μg C l^{-1} d^{-1}	PROCHLO x 10^4 ml^{-1}	CYANO x 10^4 ml^{-1}	PNF x 10^3 ml^{-1}	HNF x 10^3 ml^{-1}	CIL ml^{-1}	Source
COASTAL WATERS	Pagasitikos Gulf	0.1 – 1.0	0.05 – 4.5	_	nd – 5.3	0.1 - 5	1.4 – 10.5	0.01 – 4.2	1
	Thermaikos Gulf	0.2 - 6.8	_	_	0.1 - 5.0	0.9 – 5.1	0.6 – 2.9	0.01 - 150	2,3
	Maliakos Gulf	0.1 – 2.6	_	_	_	_	_	_	4
	Saronikos Gulf	0.3 – 5.8	0.2 – 63	_	0.1-4.9	0.2-7.9	0.2-4	0.01-5.8	5,6
OPEN SEA	South Aegean	0.4 – 1.0	0.1 – 0.8	nd –2.6	nd - 3	0.2 – 1.3	0.2- 1.9	0.005 –0.7	7,8,9
	North Aegean	0.3 – 0.7	0.4 – 1.2	_	nd – 5.6	0.6 – 1.7	0.5 – 2.7	0.002 –2.8	7,8,9

__1.__ CHRISTAKI et al., 2000; __2.__ GIANNAKOUROU et al., 2000 ; __3.__ MIHALATOU et al., 2000; __4.__ KORMAS et al., 1998; __5.__ GIANNAKOUROU & SARIDOU, 2005; __6.__ MOUTSOPOULOS, 2001; __7.__ PITTA & GIANNAKOUROU, 2000; __8.__ CHRISTAKI et al., 1999; __9.__ CHRISTAKI et al., 2001.

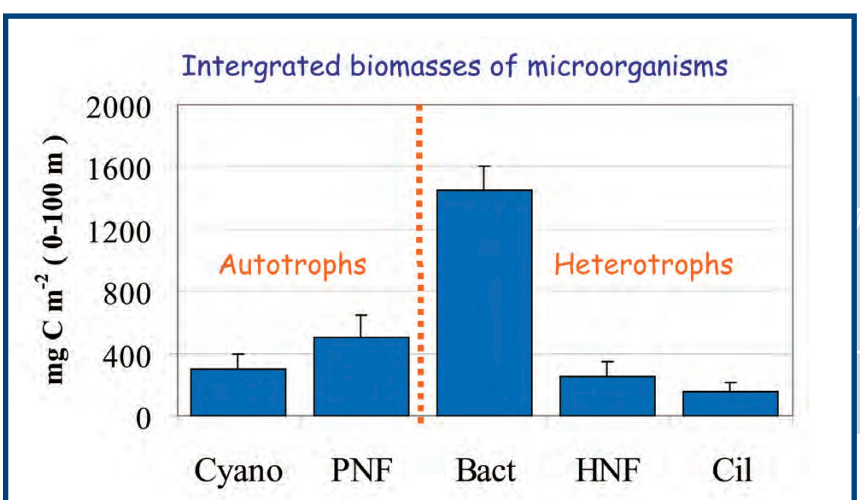


Figure V.3:
Biomass (integrated values 0-100 m) of microbial food web organisms in the oligotrophic south Aegean Sea, March 1997). CYANO: Cyanobacteria (Synechococcus spp.), BACT: Bacteria, CIL: Ciliates, PNF: Phototrophic Nanoflagellates– HNF: Heterotrophic Nanoflagellates.

COCCOID CYANOBACTERIA

In oligotrophic marine systems coccoid cyanobacteria is a dominant component of the planktonic food web. *Synechococcus* type cyanobacteria and *Prochlorococcus* are the most abundant photosynthetic organisms on the planet. Results from a trans-Mediterranean cruise in June-July 1999 recorded concentrations in the Hellenic waters varying over two orders of magnitude (10^2-10^4 cells ml^{-1}). Prochlorophytes were undetectable in surface waters and peaked deeper in the water column, near the bottom of the euphotic zone, concurring with the deep chlorophyll maximum (CHRISTAKI *et al.*, 2001). Cyanobacteria exhibited oscillations less than one order of magnitude in enclosed areas (Table V.1). Temperature is an important factor in determining *Synechococcus* distribution and can be employed for the explanation of the remarkable summer peaks at coastal sites (Figure V.4).

VIRUSES

There is little information on the occurrence, distribution and role of viruses in the Hellenic Seas. Viral densities decrease with depth and decrease also along the trophic gradient of the north to south Aegean Sea deep-sea sediments. In all cases, viral density is correlated to bacterial abundance and is higher in the sediments than the overlying water column. However, the ratio of virus/bacteria is lower in the sediments than in the water column indicating that the role played by viruses in controlling deep-sea benthic bacterial assemblages and biogeochemical cycles is less important than in pelagic systems (DANOVARO & SERRESI, 2000).

PROTISTS

Ciliate fauna in the Hellenic Seas is diverse and the ecological importance of marine planktonic ciliates is underlined with more than 100 species found. The ciliate assemblage includes members of the orders Choreotrichida (*Strobilidium* spp.) Tintinnida, Oligotrichida (*Strombidium* spp., *Tontonia* spp. and *Laboea* spp.) and Scuticociliatida. In the open Aegean Sea abundance shows a seasonal trend with a higher concentration during early and late spring and lower numbers during late summer. Ciliate density and biomass (based on volume estimates integrated in the water column down to 100 m), ranged from 2 to 2 850 ind l^{-1} and 8-112 mg C m^{-2} respectively. Cell numbers were commonly found in the order of 10^2 with the exception of the Black Sea influenced water where a sharp increase in numbers was observed in the top 20 m. The ciliate population is dominated by small aloricate forms <30 μm; thus nanociliates seem to be of major importance in the oligotrophic system of the Aegean Sea. Ciliate biomass averages 0.6-4% in relation to chlorophyll carbon. Ciliate carbon is at the lower range of values recorded from other ocean systems, indicating a possible strong top-down regulation by mesozooplankton grazers (PITTA & GIANNAKOUROU, 2000).

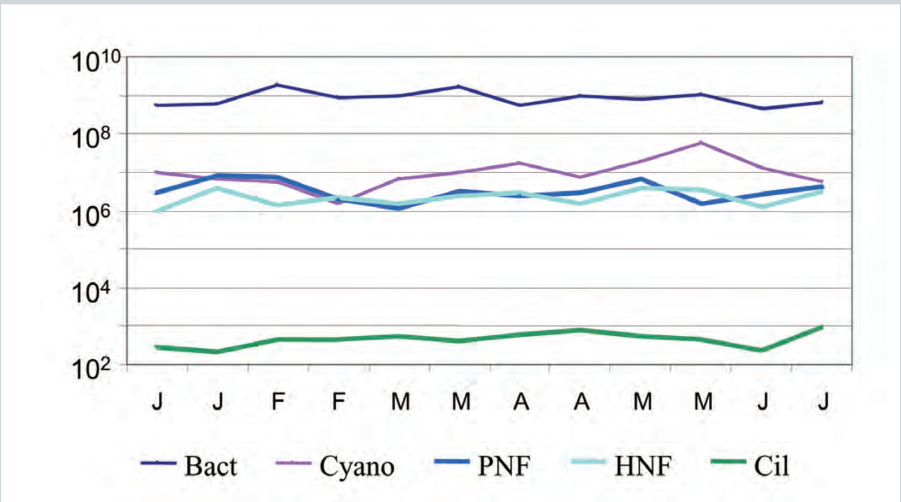


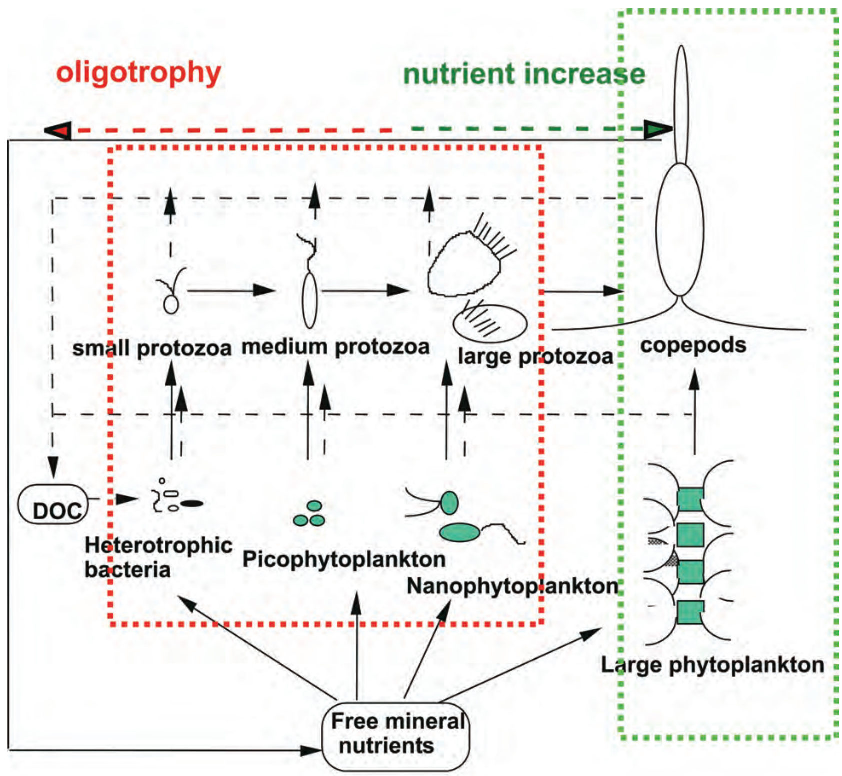
Figure V.4:
Seasonal variation of abundance (micro-organisms l-1) of microbial food web organisms in the coastal area of the Saronikos Gulf, from January to June 2002. CYANO: cyanobacteria (Synechococcus spp.), BACT: bacteria, CIL: ciliates, PNF: phototrophic nanoflagellates – HNF: heterotrophic nanoflagellates.

In coastal areas we can provide a more consistent pattern of ciliate seasonal variability. The maximal values are one order of magnitude higher than in the open sea reaching 150x10^3 cells l^{-1} (Table V.1). Ciliate numbers present fluctuations over a period of one or two weeks and there are temporal peaks in abundance. Ciliate reproductive characteristics allow for fast response to environmental changes, therefore, their population dynamics follow more closely that of phytoplankton. However, winter and summer peaks are often recorded especially for tintinnids (Figure V.4).

Many protists present a mixed nutrition involving both heterotrophy and autotrophy (mixotrophy). Ciliates may contain plastids sequestered from their phytoflagellate prey and they derive a significant portion of their carbon budget from photosyntheis performed by these plastids. Mixotrophs were found to be very important components of the ciliate community, representing 22% of the ciliate abundance in the south Aegean and 35% in the north Aegean. It is argued that mixotrophy is one of the strategies adopted in order to withstand the highly oligotrophic conditions of the Hellenic waters.

MICROBIAL FOOD WEB

The various groups of micro-organisms are associated in a more or less tightly coupled food web (Figure V.5). Open Hellenic Seas as a part of



Source: *Modified from THINGSTAD, 1998.*

Figure V.5: *Description of the planktonic food web, based on the idea of the microbial food web (Box 1).*

Box 1: *Microbial food web*

Throughout the water column **bacteria** play a key role: they contribute to the decomposition of organic material and recycling of nutrients and they are the sole users of dissolved organic matter (DOM). Bacteria are linked to the main grazing chain via the microbial loop and this serves to recover lost phytoplankton-derived DOM back to the main food web in the sea. The microbial food web introduces two different sizes of autotrophs, the **nanophytoplankton**, small flagellated blobs of chlorophyl and the **picophytoplankton**. The smallest plant cells are too small (<2μm) to be available to large suspension feeders and are consequently mostly consumed by tiny **protozoan grazers** (flagellates and ciliates), which in turn are grazed on by mesozooplankton.

the eastern Mediterranean Sea are ultra-oligotrophic. This oligotrophy is reflected in the size spectrum of organisms as the scarcity of resources forces the system towards small dimensions: dominance of pico- and nano-phytoplankton and an important role of small grazers. It has been shown that cyanobacteria are responsible for up 50% of the primary production. Due to their size these organisms are not directly available to be utilised by the crustacean dominated mesozooplankton and small grazers consume a major part of their biomass. It was estimated that small protists account for more than 90% of the heterotrophic bacterial consumption, whereas heterotrophic nanoflagellates consume up to 45% of the *Synechococcus* stock per day. Ciliates were found to consume up to 70% of the primary production in the open oligotrophic sea. Thus organic carbon and nutrients are mainly recycled within the microbial loop (Figure V.5) with a relatively low transfer of energy towards the higher trophic levels.

Concerning coastal areas, where the relative contribution of pico-phytoplankton is low, this size fraction is not negligible and it represents a significant contribution to the total budget of carbon. For example, in the Thermaikos Gulf it is suggested that microbial-web dominance increases from coastal to offshore water and from a well mixed to a stratified water column. The high proportion of microheterotrophs to planktonic biomass indicates that heterotrophic processes predominate in the system and suggests the importance of their role as carbon link to higher trophic levels. In the Maliakos Gulf there is strong evidence that the trophic web is controlled by the alternation of a eutrophic with an oligotrophic period. The end of the phytoplankton winter bloom and the depletion of nutrients lead to the dominance of pico-and nanoplankton and the increase of their grazers (KORMAS *et al.*, 1998).

EXTREME MARINE ENVIRONMENTS

The investigation of the microbiology of marine extreme environments in Hellas has been focused on the shallow hydrothermal vents (SHV) in Milos Island. In Milos SHV bacteria dominate over archaea and prokaryotic diversity is lower close to the centre of the vents (SIEVERT *et al.*, 1999). Although temperature seems to be the most important factor shaping the structure of the microbial communities, intense advection of these shallow systems might change these structures dramatically. Based on culture independent methods, *Cytophaga-Flavobacterium* and *Acidobacterium* were the most frequently retrieved bacterial groups. The sulphur-oxidiser *Thiomicrospira* spp. was found to be one of the most abundant culturable bacteria indicating the importance of the sulphur-oxidation in the ecosystem of the Milos SHV (KUEVER *et al.*, 2002). Six new species of extremophiles have been isolated from the Milos SHV. These include the hyperthermophilic Archaea *Thermococcus aegaeicus, Staphylothermus hellenicus* and *Stetteria hydrogenophila*, the thermophilic sulphate-reducing bacterium *Desulfacinum hydrothernale*, the mesophilic halophile *Filobacillus milensis* and the mesophilic sulphur-oxidiser chemolithoautotroph *Halothiobacillus kellyi*.

DEEP-SEA WATERS AND SEDIMENTS

Standing stocks of bacterial biomass in the **Hellenic deep-sea waters** are typical of oligotrophic waters. It has been found in the deep Cretan Sea that bacteria are the most important component of the biotic particulate fraction on an annual basis. Bacterial biomass also dominates **benthic systems**, suggesting that the major part of carbon flow is channelled through bacteria (DANOVARO *et al.*, 2000). Regarding other members of the microbial food web, it is known that heterotrophic nanoflagellate (HNF) distribution in the continental shelf and deep-sea sediments of the Cretan Sea is controlled by available food sources (i.e., labile organic compounds and bacteria). The high HNF abundances and their coupling with the bacterial biomass, imply that in this oligotrophic environment the transfer of energy from bacterial biomass to higher trophic levels is possible.

V.2. PHYTOPLANKTON IN PELAGIC AND COASTAL WATERS

Phytoplankton constitutes the major grouping of plants which float in the upper layers of sea water (euphotic zone) and move passively by wind or current. It is composed of microscopic algae which are predominantly autotrophic and are the primary producers of organic matter. The most important factors affecting phytoplankton growth in sea water are: light, temperature, salinity and nutrients.

Most phytoplankton organisms are unicellular but there are also colonial forms possessing individual cells of uniform structure and appearance. Phytoplankton 'categories' according to cell dimension include **Macroplankton** (more than 1 mm), **Microplankton** (less than 1 mm, retained by nets of mesh size 0.06 mm) and **Nanoplankton** (range of 3.0-60 μm).

The main taxonomic classes represented by marine phytoplankton are: Baccilariophyceae (Diatoms); Dinophyceae (Dinoflagellates) and Prymnesiophyceae (Coccolithophores). Other important classes are: Chlorophyceae, Chrysophyceae, Cryptophyceae, Cyanophyceae Euglenophyceae, Eustigmatophyceae, Prasinophyceae, Prymnesiophyceae and Rhodophyceae.

Phytoplankton stands at the base of the food chain pyramid model in sea water (Figure V.6) and there is a progressive decrease in biomass from the first trophic level (phytoplankton) towards each successive level of the pyramid (zooplankton, small fish and big fish).

In contrast to the oligotrophic conditions characterising the pelagic waters, pollution and eutrophication problems are present in a number of coastal areas because of municipal, industrial and agricultural effluents.

The present work gives a synoptic view of the status of the pelagic and coastal Hellenic waters based on biological data, such as phytoplankton biomass, community structure and primary production collected mostly in the period 1994-2002.

How we study phytoplankton?

Samples are collected from routine hydrocasts using a CTD rosette sampler from standard depths from the surface down to the euphotic zone, mainly on board the R/V 'AEGAEO'. The parameters usually measured are:

a) chlorophyll α.

b) primary productivity and cell abundance.

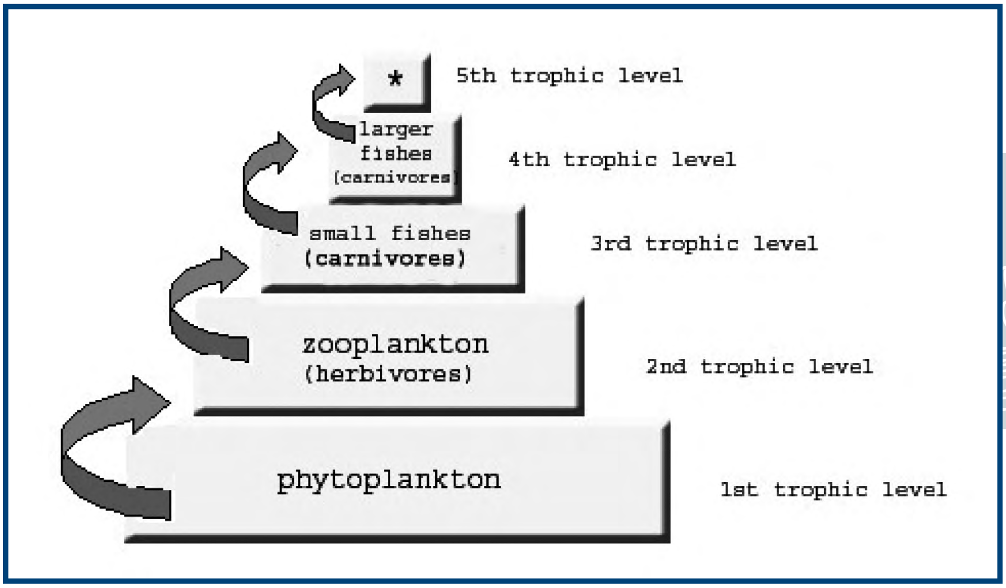


Figure V.6: *Trophic chain in the sea.*

c) Species composition.

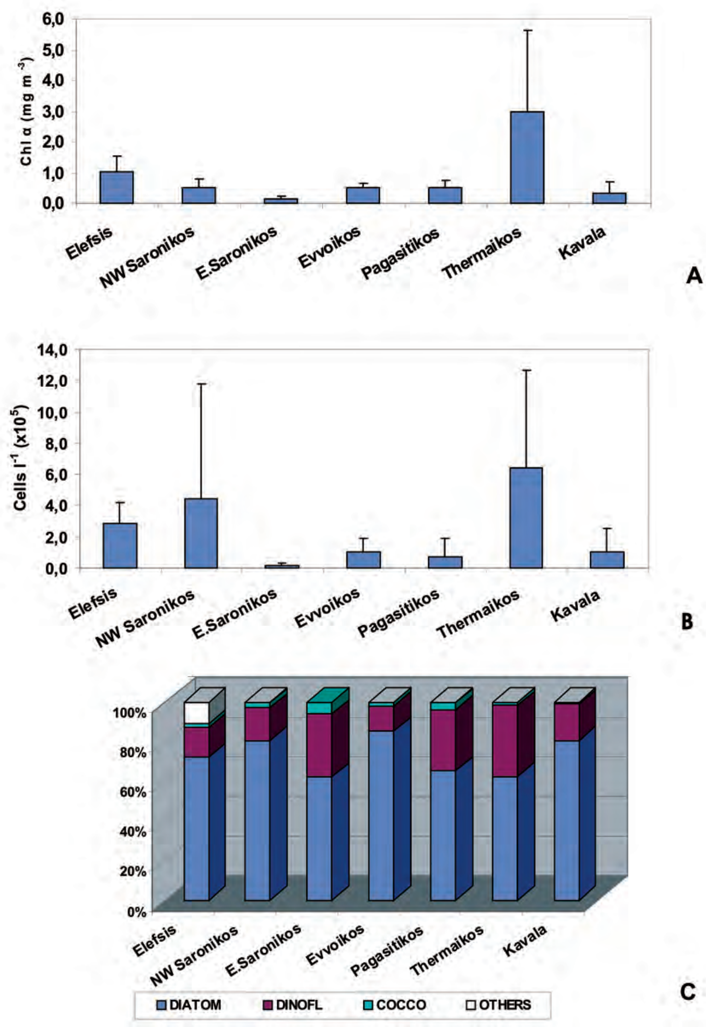
The total number of diatoms, dinoflagellates, coccolithophores, silicoflagellates and 'others' is referred to as total phytoplankton. The term 'others' refers to other taxa such as chlorophytes, chrysophytes, rhodophytes, prasinophytes and haptophytes.

COASTAL WATERS

In addition to numerous studies of phytoplankton in the framework of oceanographic studies in Hellenic waters, carried out since the 1970s, the biomass and species composition of phytoplankton were recently investigated in coastal areas of Hellas, within the framework of the EU project 'STRATEGY - new strategy and monitoring of management of harmful algal blooms in the Mediterranean Sea'.

Phytoplankton biomass (Chlorophyll a)

Figure V.7A summarises the results concerning chl a data collected from surface waters during the entire experimental period (March – November 2002) of the STRATEGY project. The mean concentration of chl a values in spring and autumn are given in Table V.2. It is seen that maxima were recorded in the Thermaikos Gulf (1.18-5.50 mg m^{-3}) and Elefsis Bay (0.54-0.69 mg m^{-3}) and minima in the eastern Saronikos (0.13-0.14 mg m^{-3}). The highest chl a concentrations were noted during the spring period.



Source: Data STRATEGY Project.

Figure V.7:
Mean annual values of A) chlorophyll a concentration, B) phytoplankton densities and C) % phytoplankton taxa in Hellenic gulfs (March-November 2002).

Population abundance and structure of phytoplankton community

The phytoplankton cell concentration data, collected from surface waters of the above gulfs during the period spring–autumn 2002, are presented in Figure V.7.B.

Phytoplankton abundance, major taxa and species composition exhibited a seasonal variation. Qualitative comparisons in terms of percentage showed that the spectrum of the major taxa in spring differed from that in autumn in all areas (Table V.3 & Figure V.7.C).

Primary production and phytoplankton biomass along a polluted gradient

The primary production of phytoplankton and the biomass (as chlorophyll α) were studied in the Pagasitikos Gulf during two oceanographic cruises in April and May 1999 (GOTSIS-SKRETAS, & ASSIMAKOPOULOU, 2000). Significantly ($p<0.01$) higher chl α concentrations and primary production rates were noted in the inner polluted Pagasitikos in comparison to the central and outer gulf. Maximum values were found at surface layers progressively decreasing with depth. Moreover, significantly higher values were noted in April than in May.

Thus, during April 1999, the average over depth chl α values presented maxima (range: 0.62-2.26 mg m^{-3}, mean: 1.37 mg m^{-3}) in the inner Pagasitikos and minima in the central gulf (range: 0.06-0.86 mg m^{-3}, mean: 0.32 mg m^{-3}). Similarly, high chl α values were recorded in May in the inner gulf (1.55 mg m^{-3}) and low values at the central and outer gulfs (0.31 mg m^{-3}). During both sampling months chl decreased from surface towards the bottom.

The PP rates presented similar fluctuations to those of chl α. The mean values in the water column varied from 0.17 to 1.02 mg C m^{-3} h^{-1} in the central and inner Pagasitikos, respectively. In May, PP

Table V.2: *Surface chlorophyll α concentrations and phytoplankton cell densities in coastal areas. (Values are station means).*

Area	SPRING		AUTUMN	
	Chlor α ($mg.m^{-3}$)	Phytoplankton ($cells.l^{-1}$)	Chlor α ($mg.m^{-3}$)	Phytoplankton ($cells.l^{-1}$)
Saronikos Gulf				
Elefsis Bay	0.54	$2.2x10^5$	0.69	$1.5x10^5$
Northwestern Saronikos	0.41	$1.4x10^5$	0.31	$9.3x10^3$
Eastern Saronikos	0.14	$4.1x10^4$	0.13	$1.9x10^3$
South Evvoikos	0.50	$8.9x10^4$	0.31	$2.8x10^4$
Pagasitikos Gulf	0.76	$3.2x10^4$	0.31	$4.1x10^3$
Thermaikos (Thessaloniki Bay)	5.50	$4.3x10^4$	1.18	$5.6x10^5$
Kavala Gulf	0.14	$3.6x10^5$	0.18	$2.5x10^4$

Source: *Data STRATEGY Project.*

Table V.3: *Dominant phytoplankton species (% of total phytoplankton) in coastal areas.*

Area	SPRING Taxon	AUTUMN Taxon
Saronikos Gulf		
	Thalassionema nitzschiodes	*Chaetoceros socialis*
Elefsis Bay	*Nitzschia delicatissima*	*Leptocylindrus danicus*
	Th. nitzschiodes	*Skeletonema costatum*
Northwestern Saronikos Gulf	*Chaetoceros curvisetus*	*Gymnodinium simplex*
	Chaetoceros curvisetus	*Th. nitzschiodes*
Eastern Saronikos Gulf	*Th. nitzschiodes*	*Nitzschia delicatissima*
	Chaetoceros affine	*Chaetoceros socialis*
South Evvoikos Gulf	*Chaetoceros socialis*	*Nitzschia closterium*
	Alexandrium minutum	*Leptocylindrus minimus*
Pagasitikos Gulf	*Prorocentrum micans*	*Thalassiothrix frauenfeldii*
	Prorocentrum micans	*Nitzschia closterium*
Thermaikos Gulf (Thessaloniki Bay)	*Prorocentrum rotundatum*	*Nitzschia delicatula*
	Leptocylindrus danicus	*Rhizosolenia fragilissima*
Kavala Gulf	*Nitzschia delicatissima*	*Leptocylindrus danicus*

Source: *Data STRATEGY Project.*

values presented smaller fluctuations varying from 0.49 in the central part to 0.54 mg C m^{-3} h^{-1} in the inner gulf. The vertical distribution of PP showed maxima at the surface layers (0.68 - 2.26 mg C m^{-3} h^{-1}) decreasing with depth.

The higher concentrations of chl α and PP rates recorded in the inner Pagasitikos should be attributed to nutrient enrichment of the inner gulf due to anthropogenic activities (KOLLIOU-MITSIOU, 1999). In general, chl α values and PP rates in the inner Pagasitikos are higher than those recorded in the Patraikos Gulf (0.39 mg C m^{-3} h^{-1}) (GOTSIS-SKRETAS *et al.*, 2001) and in the north and the south Aegean Sea and the Ionian Sea, and lower than those in Thessaloniki Bay during May 1997 (44.3 mg C m^{-3} h^{-1}) and the inner Thermaikos Gulf (1.40 mg C m^{-3} h^{-1}) (PAGOU & ASSIMAKOPOULOU, 1998). The PP values at the central and outer Pagasitikos are comparable to the Patraikos Gulf (0.39 mg C m^{-3} h^{-1}) (GOTSIS-SKRETAS *et al.*, 2001).

PELAGIC WATERS

Phytoplankton biomass (Chlorophyll α)

Table 4.A summarises the results concerning chl

Table V.4: *Chlorophyll α concentrations, primary production rates and phytoplankton cell densities in pelagic Hellenic waters. Values are averages over depth (0-100 m) and stations.*

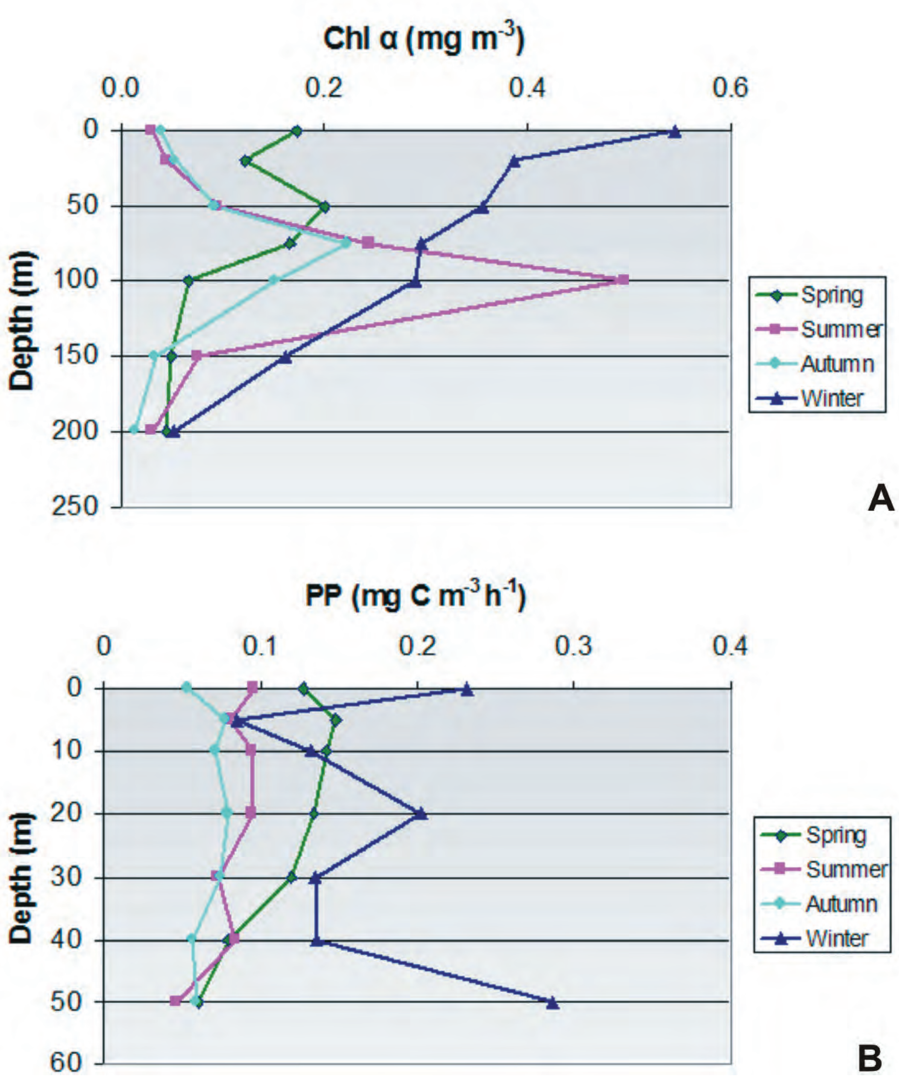
Area	Date	mean	Date	mean	Source
A.	**Chlorophyll α (mg m^{-3})**				
North Aegean Sea	March '97, '98	**0.38**	Sept '97	**0.26**	1
Central Aegean Sea	Dec '95	0.15	May '95	0.09	4
South Aegean Sea	**MEAN**	**0.24**	**MEAN**	**0.15**	1, 2, 3
Cretan Sea	March '94, '97, '98, Jan '95	0.24	June '94, Sep '94, '97	0.13	
Rodos Straits	March '94	0.26	Sept '94	0.16	
Kasos Strait	Jan '98	0.15	June '97, '98	0.11	
E. Cretan Arch	March '94, Jan '95	0.26	March '94, Jan '95	0.15	
W. Cretan Arch	March '94, Jan '95	0.20	March '94, Jan '95	0.17	
Antikythira Strait	March '94, Dec '94, Jan '98	0.25	June '94, '97, '98, Sep '94	0.16	
Myrtoan Sea	March '94, Jan '95	0.30	June '94, Sep '94	0.16	
NW Levantine Sea	March '94, Jan '95	**0.30**	June '94, Sep '94	**0.15**	3
Ionian Sea	**MEAN**	**0.18**	**MEAN**	**0.11**	3, 5
SE. Ionian	March '94, Jan '95	0.14	June '94, Sep '94	0.16	
CE. Ionian	March '99	0.23	Sep '99	0.09	
NE. Ionian	March '99	0.18	Sep '99	0.08	
B.	**Primary production (mg C m^{-3} h^{-1})**				
North Aegean Sea	March '97, '98	1.16	Sept '97	0.26	1
South Aegean Sea	**MEAN**	**0.18**	**MEAN**	**0.11**	1, 2, 6
Cretan Sea	March '94, '97, '98, Jan '95	0.28	June '94, Sep '94, '97	0.12	
E. Cretan Arch	March '94, Jan '95	0.13	June '94, Sep '94	0.09	
W. Cretan Arch	March '94, Jan '95	0.13	June '94, Sep '94	0.11	
Ionian Sea			**MEAN**	**0.15**	5
CE Ionian Sea	March '00	0.18	Sep '00	0.13	
NE Ionian Sea			Sep '00	0.26	
C.	**Phytoplankton (cell l^{-1})**				
North Aegean Sea	March '97	**$1.5x10^4$**	Sept '97	**$1.1x10^3$**	1
South Aegean Sea	**MEAN**	**$2.2x10^4$**	**MEAN**	**$1.1x10^4$**	2, 3, 8
Cretan Seai	March '94, '97	$2.8x10^4$	June '94, Sep '94, '97	$7.6x10^3$	
E. Cretan Arc	March '94, Jan '95	$2.0x10^4$	June '94, Sep '94	$1.3x10^4$	
Rodos Strait	March '94	$3.5x10^4$	Sept '94	$8.1x10^3$	
W. Cretan Arc	March '94, Jan '95	$2.5x10^4$	June '94, Sep '94	$1.7x10^4$	
Antikythira Strait	Mar '94	$1.2x10^4$	Sept '94	$1.5x10^4$	
Myrtoan Sea	Mar '94	$1.4x10^4$	June '94, Sep '94	$9.2x10^3$	
Ionian Sea	**MEAN**	**$1.6x10^4$**	**MEAN**	**$9.4x10^3$**	3, 7, 8
SE Ionian Sea	March '94	$1.4x10^4$	June '94	$1.2x10^4$	
NE Ionian Sea	Jan '91	$1.8x10^4$	Sep '91	$7.5x10^3$	

__1:__ IGNATIADES et al., 2002; __2:__ GOTSIS-SKRETAS et al., 1999; __3:__ GOTSIS-SKRETAS et al., 1996; __4:__ ASSIMAKOPOULOU et al., 1997; __5:__ GOTSIS-SKRETAS et al., 2001; __6:__ IGNATIADES, 1998; __7:__ GOTSIS-SKRETAS et al., 1991a; __8:__ GOTSIS-SKRETAS et al., 1991b.

a concentrations (means over depth and station) during winter-spring and summer-autumn. The chl a distribution showed spatial, seasonal and vertical variability. In general, all investigated areas had very low concentrations of chl a (usually less than 0.25 mg m^{-3}), thus confirming the oligotrophic character of these areas. Relatively higher concentrations were recorded in the north Aegean Sea (spring mean: 0.38 mg m^{-3}; summer mean: 0.26 mg m^{-3}). Maximum values were recorded during winter-spring and were attributed to the relatively high nutrient concentrations at the euphotic zone during this period. In summer-autumn, chl a minima (0.02-0.10 mg m^{-3}) were recorded at the surface layers (1-10 m) and maxima (2-8 times the surface values) at about 50-100 m depth (Deep Chl Maxima: DCM). The appearance of DCM during the summer period is considered to be normal in the eastern Mediterranean, because of the stratification of the water column, which usually starts in April, progresses through the summer and begins to disappear in November. In the Cretan Sea (Figure V.8) during summer-autumn, chl a maxima were noted at 75-125 depth, whereas the distribution of chl a was almost homogenised across the euphotic zone in winter. The very low surface chl a values during summer were attributed to the limited nutrient concentrations (especially phosphorus) at the surface layer.

Phytoplankton Primary Production

An example of the seasonal vertical distribution



Source: *Data PELAGOS Project.*

Figure V.8:
a) Seasonal vertical profiles of A) Chlorophyll a (mg m-3) and B) Primary Production (mg C / m-3 h -1) in the Cretan Sea (1994-95).

of primary production in the Cretan Sea is given in Figure V.8. The seasonal pattern of the distribution of the primary production (PP) in the open Hellenic waters (Table V.4.B) was similar to that of chl α distribution exhibiting spring-winter maxima and summer-autumn minima. The PP rates in the north Aegean Sea (0.48-1.84 mg C m^{-3} h^{-1}) in spring 1997 and spring 1998 were significantly higher than those in the other examined areas (IGNATIADES *et al.*, 2002). There was no consistent pattern to the vertical distribution of primary production, although in stratified conditions (summer-autumn), higher rates were generally measured at about 75-100 m depth. Generally, the PP maxima were located at shallower depths than chl α maxima.

Population abundance and structure of phytoplankton community

During studies in the Cretan Sea and the Straits (1994-95) and in the north and south Aegean Sea (1997-98), phytoplankton abundance, major taxa and species composition exhibited a seasonal variation. In all the areas examined, cell abundances (means over depth and station) were 1.5-3.7 times higher in winter-spring than in summer-autumn (Table V.4.C). Results showed that there are no significant differences in the cell abundance between areas, but mainly between seasons.

Qualitative comparisons, in terms of percentage, showed that the spectrum of the major phytoplankton taxa in spring differed from that in autumn in all areas. In spring 1997, coccolithophores dominated in the north (59%) and (46%) in the south Aegean Sea. In autumn 1997, a marked decline in phytoplankton abundance corresponded to a significant decrease of coccolithophores and small phytoflagellates in the entire area. Dinoflagellates were the dominant taxa in both areas consisting of 83% and 75% of the population in the north and south Aegean Sea, respectively. In general, during the three sampling periods, (Figure V.9) dinoflagellates dominated the entire Aegean Sea followed by diatoms and coccolithophores.

A total of 390 phytoplankton species was recorded in the north Aegean and 460 species in the south Aegean Sea. In both areas 530 species were recorded.

The most important species, according to their recurrent frequency and quantitative contribution, are listed in Table V.5.

RED TIDES

In the Aegean Sea coastal waters, the periodicity of red tide phenomena are sporadic and irregular. In the Saronikos Gulf, strong red tide events accompanied by fish death occurred during 1977-1983 as well as in 1987 and they were caused by the toxic dinoflagellate species *Gymnodinium breve* that reached concentrations up to 10^7 cells l^{-1} (PAGOU & IGNATIADES, 1990). Furthermore, a list of red tides phenomena (from the early 1980 to 1995), the blooming species (30 species) and their relation to anthropogenic eutrophication in the Saronikos and Thermaikos gulfs was presented in MONCHEVA *et al.* (2001). A detailed review on the occurrence of mucilage phaenomena (associated with diatoms) in Hellenic coastal waters during 1982-1994 is given by GOTSIS-SKRETAS (1995).

Table V.5: *Dominant phytoplankton species in pelagic waters.*

	spring	autumn
North Aegean	*Pomatodinium* sp. *Scaphodinium* sp.	*Gymnodinium heterostriatum* *Gymnodinium conicum*
South Aegean	*Chaetoceros affinis* *Chaetoceros curvisetus* *Nitzschia delicatissima* *Gymnodinium simplex* *Coccolithus pelagicus* *Cryptomonas* sp. *Nitzschia closterium* *Pseudonitzschia delicatissima* *Rhodomonas* sp.	*Calyptrosphaera globosa* *Calyptrosphaera superba* *Chaetoceros affinis* *Coccolithus huxleyi* *Pontosphaera* sp. *Thalassionema nitzschioides* *Thalassiothrix frauenfeldi*
Throughout the Aegean	*Emilliana huxleyi* *Pontosphaera* sp.	*Gymnodinium* sp. *Prorocentrum rotundatum* *Scrippsiella precaria*

Blue-green algae also were found to produce red tide blooms in the Evvoikos Gulf during September 1999 (METAXATOS *et al.*, 2003). The toxic dinoflagellate species *Alexandrium minutum* proliferated during the period spring-summer of 2002 and 2003 over a wide geographic range along the north-south Aegean Sea coastline mostly at low concentrations (average:10^2-10^3 cells l^{-1}) with one exemption (average:10^5 cells l^{-1}) of higher abundance (GOTSIS –SKRETAS *et al.*, 2002; 2003). The toxic species *Dinophysis cf acuminata* produced high blooms (up to1.0X10^6 cells l^{-1}) in spring 2004 (PAGOU *et al.*, 2004).

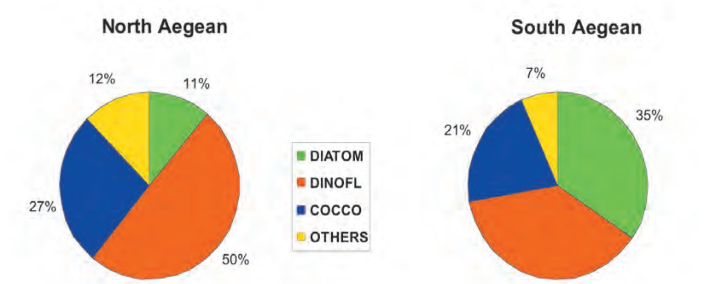
PELAGIC AND COASTAL WATERS – A COMPARISON

Figure V.10 illustrates the trophic state of the Hellenic coastal and pelagic waters on the basis of chl α (Data refer to spring sampling and values represent means over 0-120 m depth).

The waters according to chl α concentrations can be characterised as follows:

Oligotrophic:	< 0.10 mg m^{-3}
Lower Mesotrophic:	0.10-0.60 mg m^{-3}
Higher Mesotrophic:	0.60-2.0 mg m^{-3}
Eutrophic:	>2.0 mg m^{-3}

From all areas, Thessaloniki Bay, Elefsis Bay and the Amvrakikos Gulf had the highest chl α values (> 2.0 mg m^{-3}) and can be characterised as eutrophic areas. The offshore Hellenic waters with chl <0.2 mg m^{-3} can be characterised as oligotrophic, while most coastal areas are mesotrophic.



Source: *Data MATER Project.*

Figure V.9: *Annual % distribution of phytoplankton taxa in pelagic waters.*

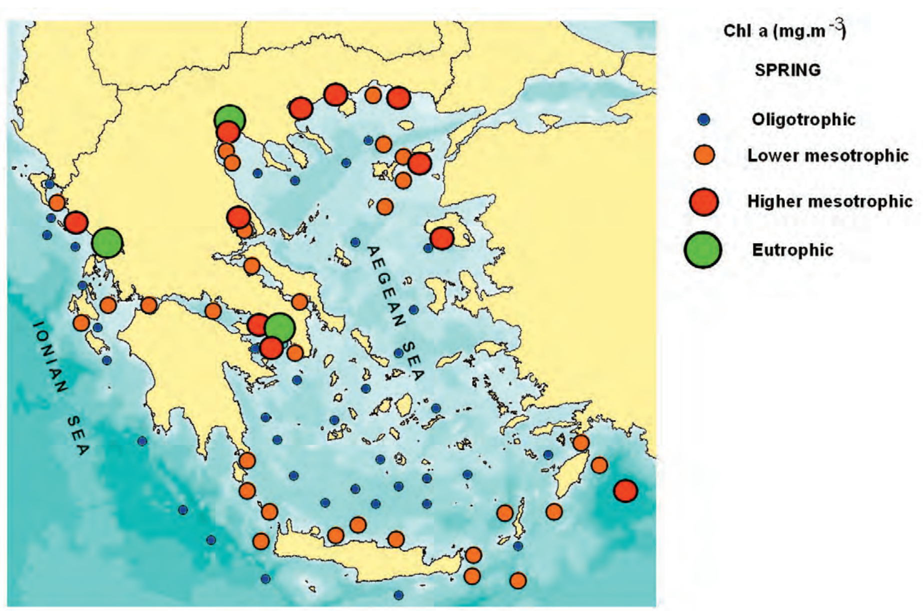


Figure V.10: *The trophic state of the Hellenic coastal and pelagic waters on the basis of chl α.*

V.3. ZOOPLANKTON COMMUNITIES IN THE HELLENIC SEAS

Mesozooplankton includes zooplankters greater than 200 μm and smaller than 2 mm, whereas macrozooplankton concerns the planktonic animals larger than 2 mm. Mesozooplankton is distinguished in meroplankton (organisms being planktonic during a part of their life e.g. larvae of benthic organisms, fish eggs and larvae) and holoplankton (organisms being planktonic during their entire life cycle).

The Hellenic Seas, because of their diversified topography and bathymetry (as described in Chapter V.1) are characterised by a great variety of habitats, thus supporting high mesozooplankton diversity. Most of the dominant mesozooplankton species in the Hellenic Seas are generally common in the Mediterranean waters.

Until the early 1970s the available information on mesozooplankton in the Hellenic waters was scant and mostly qualitative in nature (e.g. MORAITOU-APOSTOLOPOULOU 1972, 1974). The number of mesozooplankton studies in the Hellenic Seas has increased considerably since the late 1970s. Macrozooplankton has been occasionally studied either in samples collected by mesozooplankton nets or in cases of population explosions such as those of medusae and ctenophores.

Based on the available information, 367 species have been recorded in the Hellenic Seas, distributed among several taxonomic groups (Figure V.11). Meroplankton is represented by the larvae of benthic gastropods, bivalves, polychaetes, echinoderms, decapods, cirripeds as well as by fish eggs and larvae (the latter are considered as a separate group called ichthyoplankton). The number of mesozooplanktonic species recorded in the Hellenic Seas reflects both the sampling and the taxonomic effort. The best-studied groups are copepods and cladocerans, which dominate the mesozooplanktonic communities.

How we study zooplankton?

Mesozooplankton sampling is usually performed by vertical or oblique hauls of plankton nets (with mesh size varying from 180 to 280 μm) at discrete layers (0-20/50 m, 50-100 m, 100-200 m, 200-300 m, 300-500 m, 500-700 m, 700-1 000 m, 1 000 m to bottom) or from near-bottom to surface (shallow stations). It is worth mentioning that there are problems in comparing available mesozooplankton data, mainly because of inconsistencies in sampling frequency (monthly, seasonally, biannually) and

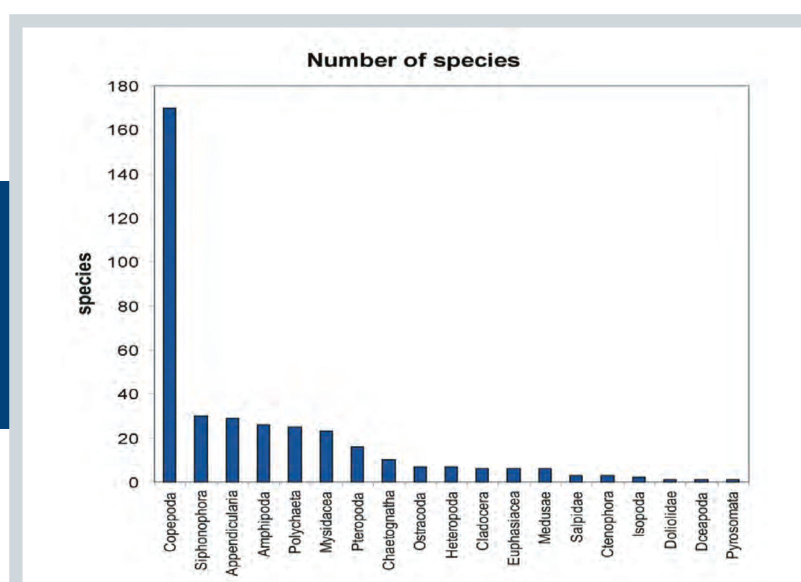


Figure V.11:
Number of species per mesozooplankton group.

sampling periods. Hence, in the present review we have tried to overcome these problems by selecting and grouping the most closely comparable data from all available sources; regarding coastal waters, as our data are mostly based on summer samples, averages are not representative of the group/species composition.

COASTAL AREAS

Quantitative aspect

In the coastal areas mesozooplankton biomass and abundance vary widely: from 1.59 mg m^{-3} (north Evvoikos Gulf) to 100 mg m^{-3} (Elefsis Bay) and from 40 ind. m^{-3} (Rodos coastal area) to 22 782 ind. m^{-3} (Amvrakikos Gulf) respectively. Based on integrated data, the minimum annual mean biomass was found in the Korinthiakos Gulf (4.14 mg m^{-3}) and the maximum in the Pagasitikos Gulf (17.06 mg m^{-3}). The Rodos coastal area has revealed the minimum annual mean mesozooplankton abundance (181 ind. m^{-3}) whereas the maximum (7 037 ind. m^{-3}) was found in Kalloni Bay (Lesvos Island) (Figure V.12). Higher biomass and abundance values were recorded in the eastern than in the western part of the Hellenic coastline. More productive, although unstable and often unpredictable, are the semi-enclosed areas in the vicinity of big cities which receive domestic and industrial wastes (Elefsis Bay, inner Saronikos, Thessaloniki Gulf and inner Pagasitikos Gulf) or fresh water inputs from rivers (e.g Thermaikos, Maliakos and north Evvoikos gulfs). Though strong spatial differentiation was found within several gulfs (Figure V.13) (Saronikos, Thermaikos and Maliakos),

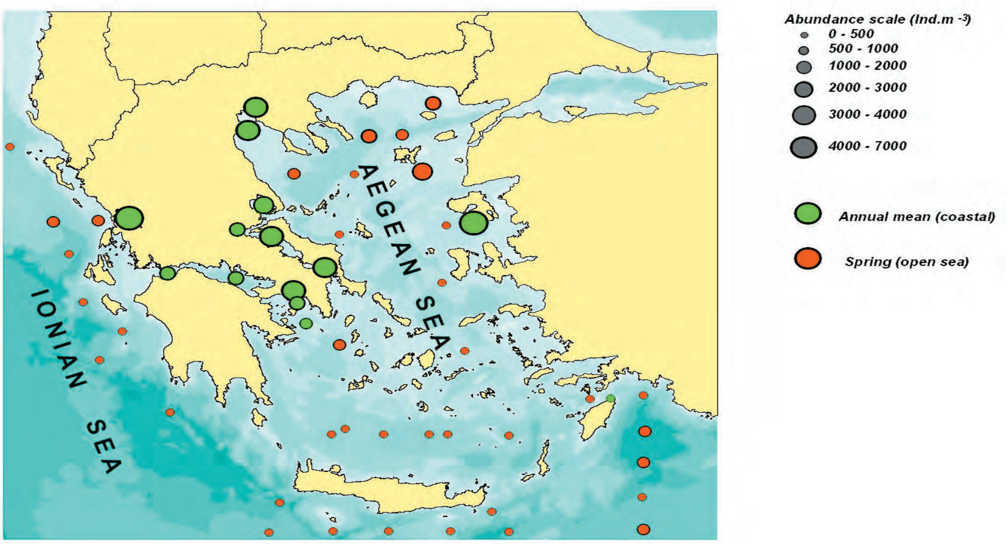
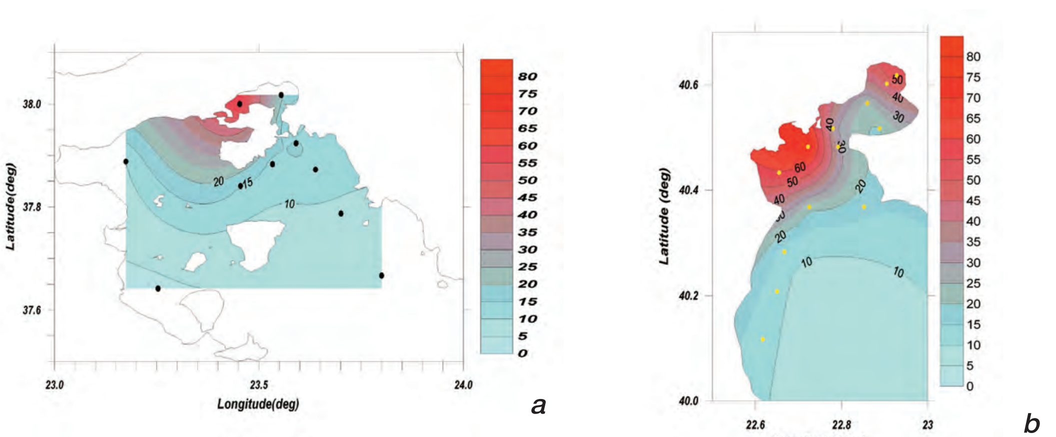


Figure V.12: *Distribution of total mesozooplankton abundance (ind. m^{-3}) in coastal and offshore waters.*



Source: *a) NCMR, 2001a ; b) NCMR, 1996.*

Figure V.13: *Spatial variability of mesozooplankton biomass (mg m^{-3}) in (a) the Saronikos Gulf (March 2001) and in (b) the Thermaikos Gulf (March 1996).*

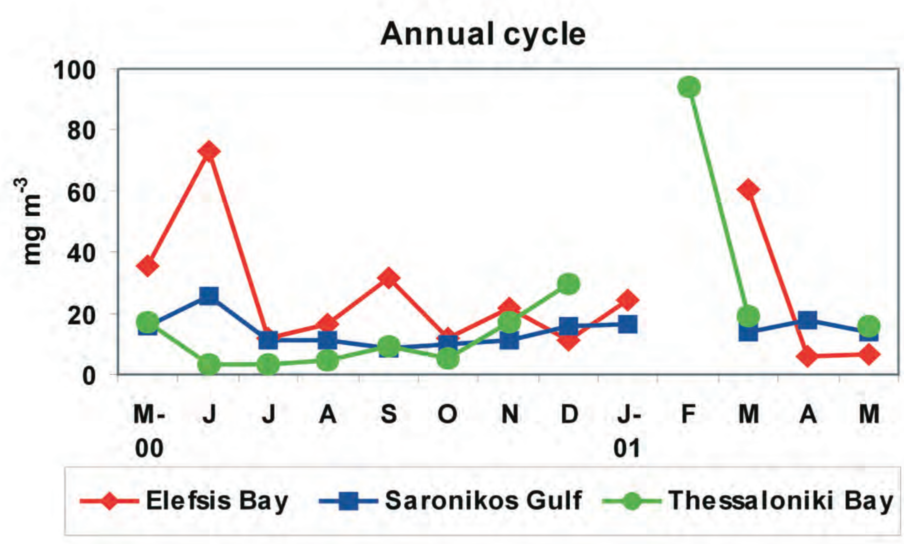
due to the differentiation of the environmental conditions and of the anthropogenic impact, the spatial pattern was not consistent over time.

Mesozooplankton biomass and abundance are characterised by pronounced seasonal variability in coastal areas, revealing a clear **annual cycle**. Generally a peak of biomass and/or abundance is observed in spring; however summer maxima are also frequent (Figure V.14). Especially in enclosed areas (Elefsis Bay, Amvrakikos Gulf and Thessaloniki Gulf) extremely high values were detected in late winter. The study of the mesozooplankton abundance **interannual** variability in the Saronikos Gulf showed consistently pronounced annual cycles throughout the whole ten-year period and a slightly increasing trend appears from 1989 to 1998 (Figure V.15).

Communities composition

a) Groups and species composition

Generally copepods dominate mesozooplankton (Figure V.16), but their contribution (relative abundance) varies markedly among areas and seasons, with high values in the cold season and low values in the warm season; the latter is due to the dominance of cladocerans in the enclosed gulfs during the summer. Meroplankton organisms are also more abundant during the summer in coastal waters, whereas appendicularians have shown large populations both in summer and in late winter-



Source: *NCMR, 2001a and b.*

Figure V.14:
Annual cycle of mesozooplankton biomass in coastal areas.

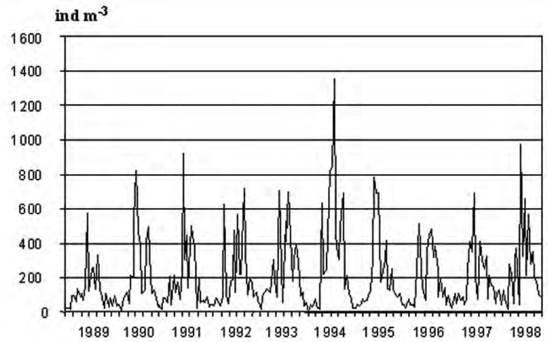


Figure V.15:
Variability of total mesozooplankton abundance (ind. m^{-3}) in the Saronikos Gulf during a ten-year period (January 1989 – December 1998) based on samples taken biweekly.

early spring (SIOKOU-FRANGOU, 1996). Among the 117 copepod species and the six cladoceran species found in the Hellenic coastal areas, a relatively small number of copepod and cladoceran species (13) comprise about half of the mesozooplankton communities throughout the year (Figure V.17). Based on samples collected in July 1998, distinct species assemblages have been defined by the mesozooplankton community analysis of central Hellenic coastal waters: the 'assemblage of the eastern part (Pagasitikos, north and south Evvoikos and Saronikos gulfs)', 'the Patraikos Gulf assemblage' and the 'Korinthiakos Gulf assemblage'. Salinity and temperature appeared to account for a significant part of the variation in community structure (RAMFOS *et al.*, submitted). In contrast, the Thermaikos Gulf, receiving the outflow of large rivers and with only weak influence from the open sea, is characterised by the relative increased abundance of neritic and euryhaline species (*Acartia clausi, Paracalanus parvus, Penilia avirostris, Podon polyphemoides*).

Few coastal areas show differences in community composition from that described above (Table V.6). Semi-enclosed and eutrophic areas receiving domestic, industrial or agricultural effluents (Elefsis Bay, Thessaloniki Gulf and Kalloni Bay) have revealed a distinct community characterised by low species diversity and high dominance of very few species. On the contrary, the community of the island of Rodos coastal area is characterised by high species number; the presence of many species

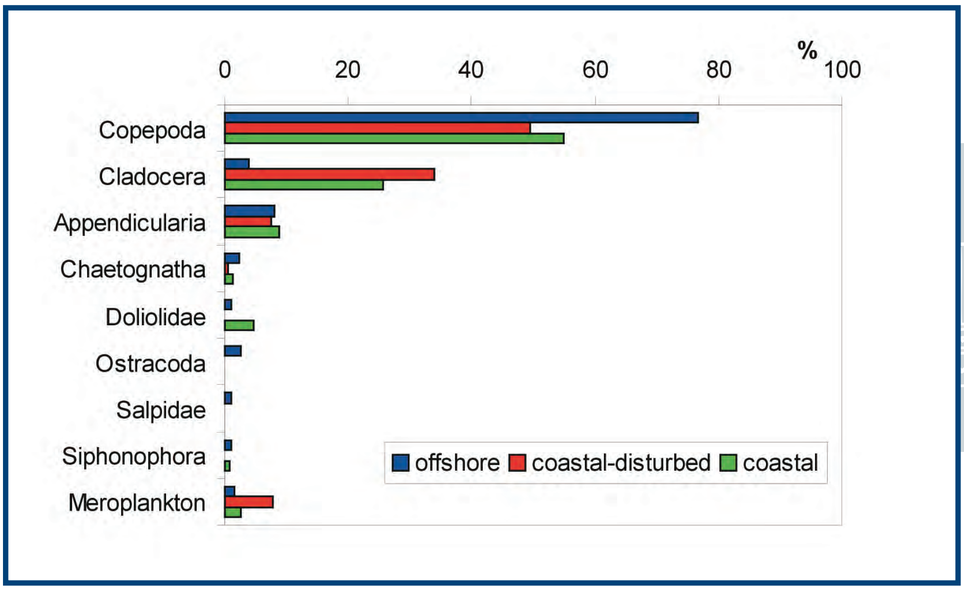


Figure V.16: *Mean relative abundances (%) of mesozooplankton groups in the offshore and coastal (non disturbed and disturbed) waters of the Hellenic Seas.*

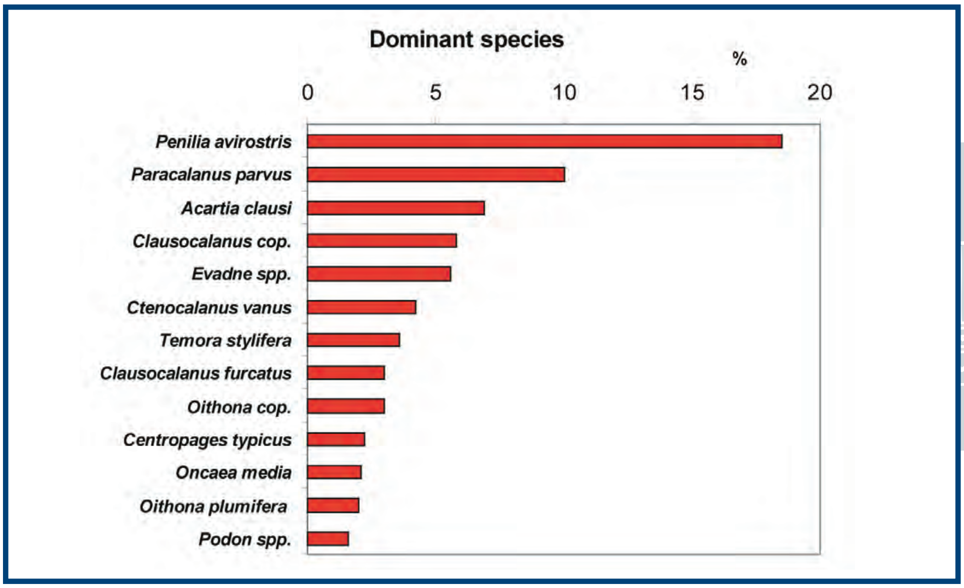


Figure V.17: *Dominant mesozooplankton species in coastal areas.*

dominant in these offshore and warm waters, attribute a pelagic and subtropical character to this community, which should be related to the large communication of the area with the neighbouring open seas (south Aegean and Levantine).

A clear seasonal variability of the community composition was observed in all coastal areas, more or less similar to that of other Mediterranean areas. The differentiation of those assemblages is attributed to the variability of the environmental parameters (e.g. temperature and influence by the open sea).

b) Species diversity and dominance

Ranges of diversity and dominance values for several Hellenic coastal areas are given in Table V.7. In confined and polluted areas (Elefsis Bay and Thessaloniki Gulf) the mesozooplankton communities have generally revealed low diversity and high dominance values when compared to other areas, thus reflecting the disturbance and sensitivity of these ecosystems. Nevertheless, diversity increases and dominance decreases in areas with little or no anthropogenic influence and with increasing influence from the open sea (e.g. in the Rodos coastal area).

OFFSHORE WATERS

Quantitative aspect

Mesozooplankton biomass and abundance are generally lower in offshore waters when compared to coastal areas (Figure V.12). A distinct pattern of decreasing mesozooplankton abundance was observed along the north-south axis in the Aegean Sea during both warm and cold seasons. The Ionian and northwestern Levantine seas revealed similar values to those of the south Aegean Sea, reflecting the intensely oligotrophic character of the eastern Mediterranean Sea (AZOV, 1986). This spatial differentiation pattern is also true for the biomass values (Table V.8). In Hellenic offshore waters the highest biomass and abundance values (up to 66.8 mg m^{-3} and 11 732 ind. m^{-3} respectively in the 0-20 m layer - May 1997) were detected in the northeastern part of the Aegean Sea, an area positioned over an extended plateau and influenced by the outflow of Black Sea waters. Within the intensely oligotrophic Levantine Sea, the Rodos Gyre is a distinct area due to the enriched mesozooplankton community in periods following a deep vertical mixing and phytoplankton bloom, e.g., in spring 1992 (SIOKOU-FRANGOU *et al.*, 1999). Based on data collected biannually from 1988 to 2000, higher values were detected in early spring

Table V.6: *Dominant species at selected coastal areas.*

Eutrophic areas (Elefsis Bay, Thessaloniki Bay, Kalloni Bay)	Oligotrophic areas (Rodos coastal area)
Acartia clausi	*Oithona plumifera*
Podon polyphemoides	*Clausocalanus furcatus*
Paracalanus parvus	*Oncaea media*
Pseudoevadne tergestina	*Oncaea mediterranea*
Centropages ponticus	*Mecynocera clausi*
Penilia avirostris	*Lucicutia flavicornis*

Table V.7: *Range of diversity and dominance index values in Hellenic coastal areas.*

Area	Diversity index Shannon-Wiener(bits $ind.^{-1}$)	Dominance Index (%)	Source
Saronikos Gulf	1.73-4.23	33-75	SIOKOU-FRANGOU, 1999
Thermaikos Gulf	1.49-3.38	33.8-68.5	NCMR, 1996
Rodos coastal area	3.58-4.58	1.4-33.7	SIOKOU-FRANGOU & PAPATHANASSIOU, 1989
Elefsis Bay	0.04-2.9	33.5-99.8	SIOKOU-FRANGOU, 1999
Thessaloniki Gulf	1.42-2.73	46.8-77.1	NCMR, 1996

than in late summer-autumn both in terms of biomass (Table V.8) and abundance.

The decrease of mesozooplankton abundance and biomass with depth is a general pattern in the oceans of world, a pattern also observed in the Hellenic Seas. A sharp decrease of abundance was observed in the north Aegean Sea between 50 and 200 m whereas the vertical distribution pattern seems to be almost similar in the south Aegean, the east Ionian and the northwestern Levantine seas (Figure V.18). Values detected between 500 m and 1 000 m are over 10 times lower than in the uppermost layer, with <1 ind. m^{-3} found below 1 000 m. Diurnal mesozooplankton vertical migration was identified both for pelagic waters on a broad scale and neritic waters (FRAGOPOULU & LYKAKIS, 1990) on a smaller scale.

Community composition

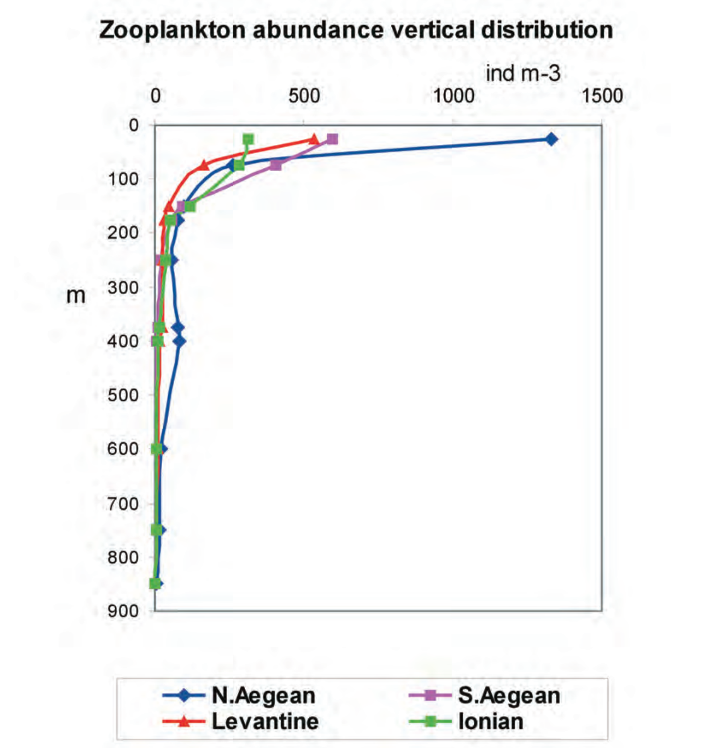
Copepods are by far the most dominant group in all seas, but in the north Aegean Sea their relative abundance decreases considerably (down to 30%) in the 0-50 m layer during the warm period, when cladocerans are dominant (up to 51% of the total mesozooplankton). Cladoceran abundance is less important in the south Aegean and much less in the other seas. Appendicularians are present mostly in the epipelagic layer (0-100 m), whereas the contribution of chaetognaths and ostracods increases from the surface down to 500 m (MAZZOCCHI *et al.*, 1997).

Copepod species distribution shows clear vertical zonation in all areas, a pattern common in the oceans of the world. Distinct assemblages were found in the epipelagic, mesopelagic and bathypelagic zones

Table V.8: *Biomass values ranges (mg m^{-3}) in the 0-100 m layer of Hellenic offshore waters.*

Season	Area N. Aegean (1997)	S. Aegean (1997)	Ionian (2000)
spring	8.4-20.5	4.5-7.2	1.2-5.5
autumn	4.8-12.8	3.6-7.2	2.4-4.6

Source: *Unpublished NCMR Data.*



Source: *Unpublished NCMR Data.*

Figure V.18:
Vertical distribution of mesozooplankton abundance (ind. m^{-3}) in the north Aegean and south Aegean Sea (March 1997), in the northwestern Levantine and east Ionian Seas (March 1988).

(Table V.9). Moreover, spatial differentiation was detected among areas in the epipelagic zone: the north Aegean Sea community is distinct from that of the south Aegean, Ionian and Levantine seas, whereas more similarities appear in the mesopelagic and bathypelagic layers. Overall the mesozooplanktonic community of the north Aegean Sea is distinct within the eastern Mediterranean Sea, probably related to the topography, the hydrology and the water mass circulation in the area (SIOKOU-FRANGOU *et al.*, 2004).

MACROZOOPLANKTON

Studies on macrozooplankton in Hellenic waters are sporadic and mainly concern species or groups which attracted research interest due either to their massive occurrence and/or their impact on human activities or ecosystem functioning. Among the studied macrozooplanktonic organisms are medusae, ctenophores and euphausiids.

Medusae blooms

Large population swarms of the scyphomedusa *Pelagia noctiluca* (Figure V.19) were detected all around the Hellenic coastline in 1981-1983. Similar aggregations were observed during the same period in the Adriatic Sea, the east Ionian Sea and the Ligurian Sea. The analysis of chronological series revealed that the bloom occurrence of *P. noctiluca* in the Mediterranean Sea is not a recent

Table V.9: *Copepod dominant species in the Hellenic seas.*

Area / Season / Layer	N. Aegean: Cold period	N. Aegean: Warm period	S. Aegean: Cold period + Warm period
Epipelagic (0-100m)	*Clausocalanus paululus* *Clausocalanus pergens* *Centropages typicus* *Acartia clausi* *Clausocalanus parapergens*	*Penilia avirostris* *Temora stylifera* *Evadne spinifera* *Oncaea media* *Farranula rostrata*	*Clausocalanus furcatus* *Clausocalanus paululus* *Farranula rostrata* *Oithona plumifera* *Oithona setigera* *Oncaea media*
Mesopelagic (100-500m)	*Clausocalanus paululus* *Oithona setigera* *Lucicutia flavicornis* *Pleuromamma gracilis* *Lucicutia gemina*		*Oithona setigera* *Haloptilus longicornis* *Lucicutia flavicornis* *Pleuromamma gracilis* *Spinocalanus* spp. *Lucicutia gemina*
Bathypelagic (500-2000m)	*Calanus helgolandicus (N. Aegean)* *Eucalanus monachus (S. Aegean)* *Oncaea ornata* *Monacilla typica* *Spinocalanus* spp. *Mormonilla minor*		

Area / Season / Layer	Ionian: Cold period + Warm period	NW Levantine: Cold period + Warm period
Epipelagic (0-100m)	*Clausocalanus furcatus* *Clausocalanus paululus* *Oithona plumifera* *Farranula rostrata* *Oithona setigera* *Oncaea media*	*Clausocalanus furcatus* *Clausocalanus paululus* *Oithona plumifera* *Oithona setigera* *Farranula rostrata* *Oncaea media*
Mesopelagic (100-500m)	*Haloptilus longicornis* *Oithona setigera* *Oncaea mediterranea* *Lucicutia flavicornis* *Lucicutia gemina* *Pleuromamma gracilis*	
Bathypelagic (500-2000m)	*Eucalanus monachus* *Spinocalanus* spp. *Mormonilla minor* *Oncaea* sp.	

phenomenon, but rather a normal and recurring event, a biological expression of the pelagic ecosystem in response to the fluctuations of the environment physical parameters (UNEP, 1991). On the other hand, the occurrence of large populations of the scyphomedusae *Aurelia aurita and Rhizostoma pulmo* in Elefsis Bay (the former) and in the Thessaloniki Gulf and inner Thermaikos Gulf (both) should be related to their successful adaptation to the eutrophic conditions of these areas (PAPATHANASSIOU *et al.*, 1987).

Ctenophores

In the early 1980s, the predator ctenophore *Mnemiopsis leidyi* was introduced by (VINOGRADOU *et al.*, 1992) ballast waters into the Black Sea, where it exerted a tremendous impact on the pelagic ecosystem. Regarding the Aegean Sea, this species was first recorded in the Saronikos Gulf during late spring-summer 1990 (45-75 ind. m^{-2}). Since then its abundance was decreasing until 1996 and, after this year, became rare in the area (SHIGANOVA *et al.*, 2001). However, a large swarm was recorded in January 1998. *M. leidyi* was rather abundant (3 ind. m^{-2}) in May 1995 in Kalloni Bay (Lesvos Island). In June 1988 its abundance was 1.5 - 2.5 ind. m^{-2} in the northeastern Aegean and in September 1998 its greatest abundance was recorded close to the Dardanelles Strait (2.5 ind. m^{-2}). Also swarms were observed during the summer in several coastal areas of the Aegean Sea (Skyros, Limnos and Alonnisos islands and the Chalkidiki Peninsula) between 1991 and 1996. (SHIGANOVA *et al.*, 2001). During the last years *Mnemiopsis* swarms were recorded mostly around Limnos Island as well as in the north Evvoikos Gulf (Figure V.20). In general, the abundance of

Photo: *A. FRANTZIS.*

Figure V.19: *The scyphomedusa Pelagia noctiluca.*

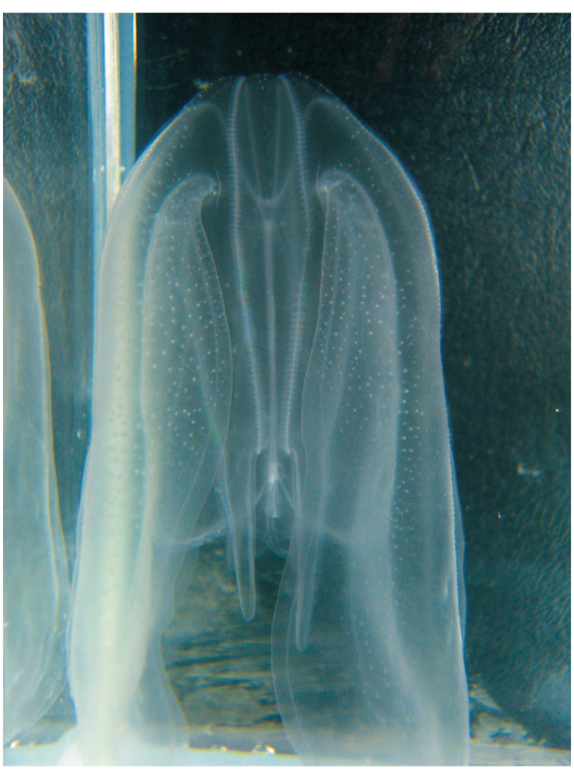


Photo: *E.D.CHRISTOU.*

Figure V.20: *Ctenophore Mnemiopsis leidyi.*

Mnemiopsis in the north Aegean Sea (max 150 ind. m^{-2}) was found to be much lower when compared to the Black Sea (max 7600 ind. m^{-2}, VINOGRADOV *et al.*, 1989).

The presence of *Mnemioposis* in the Aegean is mainly attributed to the Black Sea water entrance into the northern Aegean Sea. The size of individuals collected in the Aegean waters (2-14 cm), was smaller than those observed in the Black Sea (SHIGANOVA *et al.*, 2004).

Recent unpublished experimental work suggests that the reproduction rate of *Mnemiopsis* is highest in the Black Sea and lowest in the Aegean Sea, although weight specific reproduction is highest in the Caspian Sea and lowest in the Aegean Sea. The lower reproduction rate in the Aegean Sea was attributed to both the lower prey concentration (mesozooplankton) and the higher salinity in the area. The respiration rate was also lower in the Aegean and the Caspian Seas than in the Black Sea, which is probably related with the different osmoregulation resulting from the great differences in salinity.

Euphausiids

Euphausiids can make a large contribution to the plankton biomass throughout the year and are considered to be an important source of food for plankton feeding fish populations (WILLIAMS & FRAGOPOULU, 1985). In Hellenic waters euphausiids have been recorded in the coastal waters of the Patraikos Gulf (Ionian Sea) and pelagic waters of the north Aegean Sea. In the Patraikos Gulf *Nyctiphanes couchi* was found to migrate at night during the development of the seasonal thermocline, while ontogenetic migrations of the species were also detected (FRAGOPOULU & LYKAKIS, 1990). The study of qualitative and quantitative samples taken at 250-1 000 m depths in the north Aegean Sea (using a midwater trawl) revealed the presence of 8 species, among which *Nematoscelis megalops* was the most abundant at 500 m depth (MAVIDIS *et al.*, 2004).

BIOLOGICAL CYCLE AND METABOLISM

Four to five generations of *A. clausi* were found throughout the year in the Saronikos Gulf; the mean generation length estimated at 28.6 d, which was among the highest recorded in the literature for *A. clausi* at the range of temperatures encountered in the area (13˚C - 25˚C) (CHRISTOU & VERRIOPOULOS, 1993). Studies of respiration, ammonium and phosphate excretions of mesozooplankton populations in a coastal area of the Saronikos Gulf revealed lower metabolic rates than those reported for the western Mediterranean; this might be related to the higher oligotrophy in the eastern Mediterranean (CHRISTOU & MORAITOU-APOSTOLOPOULOU, 1995).

SECONDARY PRODUCTION

The northeastern Aegean Sea showed the highest copepod production while production between the rest of the north Aegean and the south Aegean was comparable (Table V.10). The increased production of the northeast Aegean should be mainly related to the influence from hydrology (frontal area) and topography (extended continental shelf).

THE ROLE OF MESOZOOPLANKTON IN THE PLANKTONIC FOOD WEB

Within the pelagic food web mesozooplankton is the link between the lower level producers (phytoplankton, microbes) and the top predators (fish). The study of the carbon flow through the pelagic food web in the Aegean Sea in spring 1997 revealed a differentiation of the mesozooplankton contribution along the north-south axis: copepods have been found to consume a greater proportion

Table V.10: *Production of copepod community (mgC m^{-2} d^{-1}) in northeast Aegean (NEA), rest of north Aegean (NA) and south Aegean (SA).*

	NEA	NA	SA
Spring 1997	41	5	5
Autumn 1997	58	15	6

Source: *unpublished NCMR data.*

of the larger cell production in the south Aegean Sea (14%) than in the northeastern (6.2%) and the northern (1%). The above findings, related to the very low ciliate biomass found in the northeastern and northern Aegean Sea, suggest a strong grazing control of the latter by copepods in these areas; therefore, a microbial food web seems to have been developed in the northeastern and northern Aegean Sea, whereas the food web in the southern Aegean could be classified as multivorous [where both herbivorous and microbial grazing modes have significant roles (SIOKOU-FRANGOU *et al.*, 2002]. The dominance of cladocerans and the important presence of appendicularians (both able to feed on pico- and small nanoplankton) during summer in the north and northeastern Aegean Sea, imply more efficient pathways within the food web in the above areas. This assumption, together with the increased mesozooplankton biomass and copepod production, suggests that there is a better transfer of energy towards mesozooplankters in the north Aegean than in the south Aegean. Therefore, we may assume that this difference in the degree of energy transfer will be reflected in the higher trophic levels, fish and benthos.

CONCLUSIONS

- ***Coastal waters:*** The most productive coastal areas in terms of mesozooplankton abundance and biomass seem to be the enclosed or semi-enclosed bays and gulfs affected by anthropogenic inputs, such as the Amvrakikos and Thermaikos (especially the inner part) gulfs as well as Elefsis Bay which are characterised by the highest mesozooplankton abundance and biomass. Except for the coastal areas, which are largely influenced by the open sea, the standing stocks, in general, are similar to those found in other Mediterranean areas. The same is also true for the species assemblages.
- ***Offshore waters:*** The higher standing stocks were recorded in the northeastern Aegean Sea whereas the south Aegean, the Ionian and Levantine seas are areas with low mesozooplankton abundance values, reflecting the intensely oligotrophic character of the eastern Mediterranean Sea. A similar differentiation among areas is also true for the species assemblages in the epipelagic and the bathypelagic layer, whereas the mesopelagic assemblages appear to be more or less uniform. The standing stock and the community composition seem to be affected by the hydrological features of the basins.

V. GAPS IN KNOWLEDGE - FUTURE PERSPECTIVES

Open Hellenic Seas as a part of the eastern Mediterranean Sea are ultra-oligotrophic, with low nutrient concentration and low primary productivity where the role of micro-organisms within the microbial food web seems to be crucial. Available information on the microbial ecology of the Hellenic Seas is rather fragmentary, with not enough studies of the coastal systems and marine sediments being carried out. The bulk of the available data refers mainly to the open sea. At the organism level, diversity and function of prokaryotes should attract more interest. The scientific achievements of molecular microbiology of the 1990s, namely the 16S rRNA gene and fluorescent *in situ* hybridisation (FISH), could provide us with ample data on the role of marine micro-organisms in the biogeochemical cycling and obtain insights into other ecological and possible biotechnological applications as well.

Phytoplankton studies should include work in the Ionian Sea, a region where information on phytoplankton ecology is scanty. Attempts should be made to relate phytoplankton to the food web of the pelagic ecosystem. Population explosions, especially in connection with red tide phaenomena, should be studied. Given the fact that the phytoplankton communities are continuously changing quantitatively and qualitatively because of changes in several environmental parameters (climatic changes, nutrients, pollution) work on time-series collections and analyses should be continued.

There is a lack of information on the species composition and ecology of mesozooplankton concerning groups other than copepods and cladocerans. Macrozooplankton is poorly known whereas there are very few studies on the copepod production, grazing impact and metabolism.

The role of mesozooplankton as a link between the lower trophic levels (phytoplankton, microbes) and the higher trophic level (fish) has to be investigated both in coastal and offshore waters.

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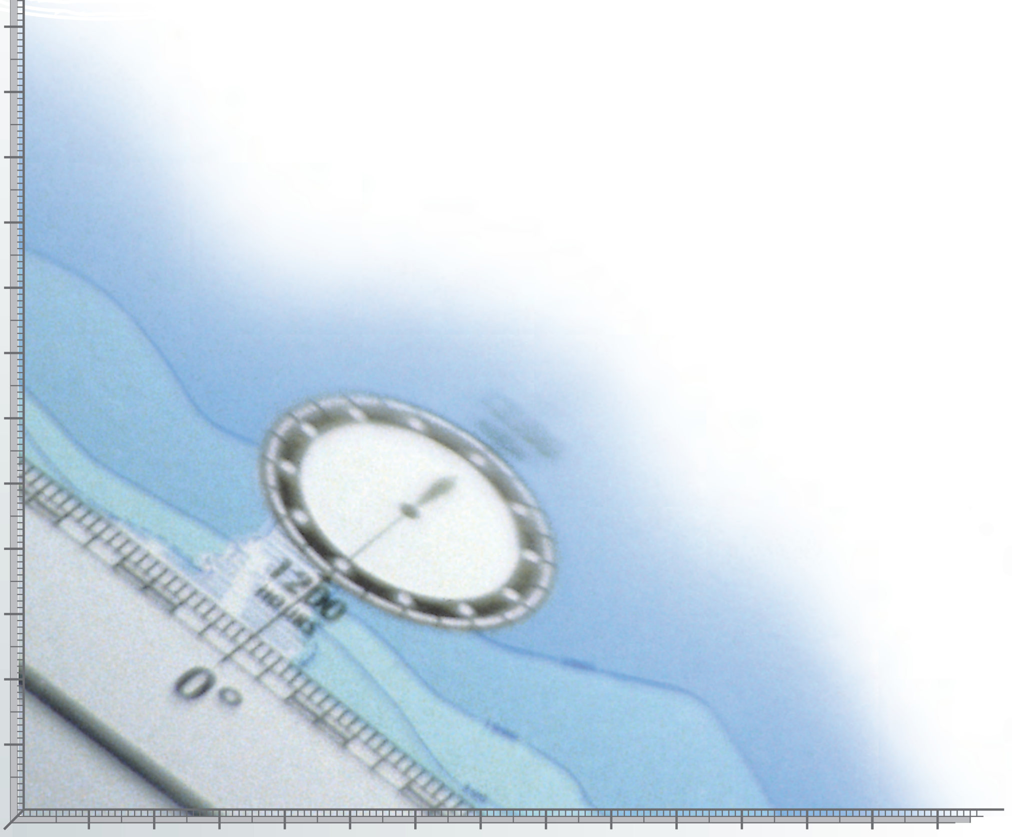
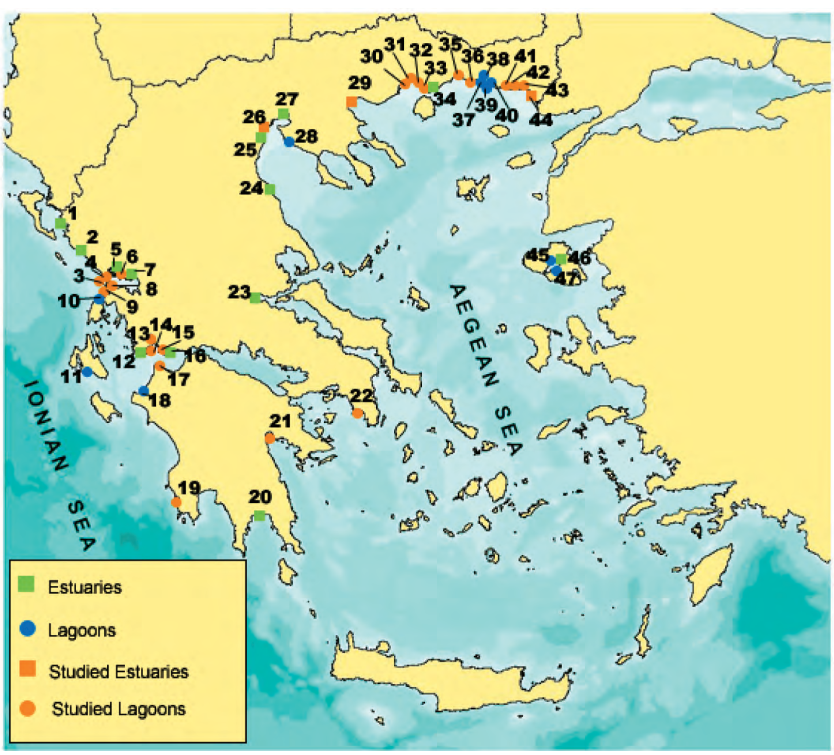
CHAPTER VI
BIOTA OF THE SEA BED



VI.1. LAGOONS

The most extensive lagoonal systems are located in western and northern Hellas (Figure VI.1). The most important are protected under the Ramsar convention and/or are part of the Natura 2000 network. Almost all are used for the extensive culture of fish (Table VI.1). The Hellenic lagoons are not all equally explored scientifically. More attention has been given to the lagoons of the Amvrakikos Bay, while the most comprehensive study was carried out in Gialova, in the southwest Peloponnisos.

Being enclosed, shallow areas, the lagoons are characterised by frequent fluctuations in environmental parameters on a daily and seasonal basis (Table VI.2). In this sense, coastal lagoons can be considered as harsh, naturally stressed environments. This natural instability discourages the settlement of many organisms, thus, the lagoons present a generally low number of species and low diversity. On the other hand, they are organically enriched areas, both as a result of river input and recycling of materials within the system. Hence, a large number of individuals and high biomass is attained.



1: Kalamas Est.	13: Aitoliko Lag. (*)	25: Aliakmonas Est.	37: Karatza Lag.
2: Acherontas Est.	14: Mesolongi Lag. (*)	26: Axios Est.	38: Alyki Lag.
3: Mazoma Lag. (*)	15: Kleisova Lag. (*)	27: Gallikos Est.	39: Ptelea Lag.
4: Tsopeli Lag. (*)	16: Evinos Est.	28: Epanomis Lag.	40: Elos Lag.
5. Louros Est.	17: Araxos/Papas Lag. (*)	29: Strymonas Est.	41: Laki Lag. (*)
6. Rodia Lag. (*)	18: Kotychi Lag.	30: Vassova Lag. (*)	42: Drana Lag. (*)
7. Arachthos Est.	19: Gialova Lag. (*)	31: Erateinou Lag. (*)	43: Monolimni Lag. (*)
8. Logarou Lag. (*)	20: Evrotas Est.	32: Agiasma Lag. (*)	44: Evros Est. (*)
9. Tsoukalio Lag. (*)	21: Vivari Lag. (*)	33: Keramoti Lag. (*)	45: Alyki Kallonis Lag.
10. Stenou Lefkadas Lag.	22: Vouliagmeni Lag.	34: Nestos Est.	46: Vouvaris Est.
11: Koutavos Lag.	23: Spercheios Est.	35: Porto Lagos Lag.	47: Alyki Polychnitou Lag.
12: Acheloos Est.	24: Pineios Est.	36: Fanari or Xsirolimni Lag. (*)	

Figure VI.1: *Map of Hellas showing the main transitional coastal ecosystems (estuaries and lagoons). Asterisks indicate ecosystems for which detailed information exists and are treated in this work.*

Table VI.1 *Conservation status, exploitation and research carried out in Hellenic lagoons.*

LAGOONS		Amvrakikos Gulf					Patraikos Gulf		
		Ma	T	Ts	R	L	Me	A	P
Size (km)		1,6	1	16,5	13,5	25,7	100	26	3
Exploitation		AE, F	F, AE, ASI	F, AE, ASI	F, AE, ASI	F, AE, ASI	F, AE	F, AE	F, AB, AE
Conservation		R,N	R,N	R,N	R,N	R,N	R,N	R,N	N
Human impact								DC	DC
Parameters studied	Abiotic	*	***	***	***	***	***	***	***
	Plankton				**				
	Phytobenthos	*	**	**	**	**	**	**	**
	Zoobenthos	*	***	***	***	***	***	***	***
Source		NICOLAIDOU *et al.*, (2005)					REIZOPOULOU & NICOLAIDOU, 2004		

LAGOONS		Ionian Sea	Eastern Makedonia & Thraki					Evros Delta
		G	Va	E	Ag	Ke	F	
Size (km)		2.5	0,8	3,0	3,9	1,0	1,9	
Exploitation		F, AE	F, AE, AB	F, AE, AB	F, AE	F, AE	F	F
Conservation		N	R,N	R,N	R,N	R,N	R,N	R,N
Human impact		DC	SL	SL				
Parameters studied	Abiotic	***	*	*	*	*		***
	Plankton	**						
	Phytobenthos	*	**	**	**	**	*	**
	Zoobenthos	***						***
Source		KOUTSOUBAS *et al.*, 2000	ORFANIDIS *et al.*, 2000 & 2001					KEVREKIDIS & KOUKOURAS, 1988

Notes: (A=Aetoliko, Ag=Agiasma, E=Eratino, F=Fanari, G=Gialova, Ke=Keramoti, L=Logarou, Ma= Mazoma, Me=Mesolongi, P=Papas, R=Rhodia, T=Tsopeli, Ts=Tsoukalio, Va=Vassova),(F=Fisheries, AE=Extensive aquaculture, ASI=Semi-intens. aquaculture, SLW=Saltwork, AB=algal bloom, DC=dystrophic crisis, SL=sea grasses loss, OEN=organic enrichment), =RAMSAR, N=NATURA); * =occasional, ** =seasonal, *** =seasonal, more than one year.

Table VI.2 *Environmental and ecological characteristics of Hellenic lagoons.*

LAGOONS	Amvrakikos Gulf					Patraikos Gulf			
	Ma	T	Ts	R	L	K	Me	A	P
Depth (m)	1.0 – 2.0	0.2 – 1.5	1.6 – 5.2	2.9 – 5.2	0.7 - 1.0	0.20 – 2.0	0.20 – 2.0	0.30 – 30.0	0.20 - 1.5
S	23.0 – 27.0	21.0 – 38.0	14 – 36.5	5.0 - 35.0	15.8 - 48.6	23.0 – 41.0	37.0 – 45.0	18.5 - 23.5	20.0 – 42.5
T ˚C	9.0 – 13.0	8.0 – 29.0	8.6 – 30.0	8.9 - 29.1	9.1 – 28.1	20.5 – 21.6	24.5 - 27.9	15.5 -25.3	10.0 – 32.0
O_2 (mg/l)	4.8 – 6.8	2.8 – 9.8	4.6 – 10.6	3.5 – 10.8	4.5 – 12.1	5 – 6.7	4.2 – 7.9	4.5 – 7.3	1.2 – 9.3
Coarse %	–	6.7 – 66.3	6.3 – 79.0	12.0 – 77.5	6.4 – 32.0	19.9 – 35.6	2.0 – 76.8	9.1 - 11.1	23.0 - 98.0
Org. C %	–	0.6 – 2.7	1.3 – 5.1	1.2 - 5.0	2.2 - 3.5	1.6 - 3.6	0.9 - 5.1	2.4	2.9 – 5.6
No species (S)	8 – 39	5 – 45	4 – 29	3 – 17	11-31	11-14	9-42	0 - 12	0 - 44
Diversity (H')	2.1 – 3.5	1.3 – 3.7	1.9 - 3.3	0.8 – 3.0	0.4 - 3.3	2.2 – 3.3	2.7 – 4.1	1.2 – 2.3	1.7 – 3.7

LAGOONS	Ionian Sea	Eastern Makedonia & Thraki			Evros Delta				
	G	V	E	F	C	La	Mo	D	I
Depth (m)	0.3 – 1.2	0.2-4	0.2-3	0.2-2	0.15 – 0.40	0.05 –0.5	0.30 – 0.85	0.2 – 0.85	0.2 – 0.95
S	13 – 60	26.1-34.6	19.3-34.2	34-55.9	4.0 – 25.0	0.1 – 6.8	0.3 – 5.7	0.8 – 8.7	24.0 – 36.0
T ˚C	14-31	2-31.5	2-31.5	9-31.4	12.6 – 24.5	6.7 – 25.9	1.8 – 28.5	2.0 – 34.0	3.4 – 26.9
O_2 (mg/l)	4.5 – 9.1	4.2-22	4.3-15.2	5.4-15.1	–	5.3 – 13.7	6.1 – 18.0	10.3 – 15.6	5.3 – 8.4
Coarse %	14.5-94.7	–	–	–	147 – 208*	63 – 153*	94-176*	79 – 164 *	63 – 104 *
Org. C %	0.2-5.0	1.1-3.8	2-3.9	0.20 – 1.95	0.37 – 1.32	0.31 – 1.66	0.15 – 2.20	0.10 – 2.03	0.86 – 2.54
No species (S)	22-87	1-10 ***	1-7***	1-5***	12 – 23	7 – 12	6 – 12	2 – 8	4 – 8
Diversity (H')	1.9-3.4	0-2.3 (e)	0-1.95(e)	0-0.99 (e)	1.5 – 3.1	0.8 – 1.7**	0.7 – 2.2**	1.2 – 1.8**	0.5 – 1.3

Notes: Number of species based on different total sample size. Shannon-Wiener diversity based on log_2 except where ** :loge ***: benthic macrophytes,(Aetoliko, Ag=Agiasma, C=Coast, D=Drana, E=Eratino, F=Fanari, G=Gialova, I=Isolated shallows, K=Klissova, Ke=Keramoti, L=Logarou, La=Laki, Ma= Mazoma, Me=Mesolongi, Mo=Monolimni, P=Papas, R=Rhodia, T=Tsopeli, Ts=Tsoukalio, Va=Vassova); =Median diameter (φ) .

PLANKTON

The phytoplankton, in terms of species composition (Table VI.3), is poorer than neritic phytoplankton. It is frequently enriched by benthic diatoms, which, due to the small depth of the lagoons, are put in suspension by the wind. In addition, neritic species enter passively from the sea and remain in the lagoon for a period of time. Thus, in the most enclosed lagoons, for example, in Rodia of Amvrakikos, cryptophytes are the most abundant genera. Where communication with the sea is greater, as in Logarou, the dominant species belong to the diatoms. In semi-enclosed lagoons, such as Gialova, the diatoms are rather few, restricted to the marine channels, while dinoflagellates are quite well represented especially in the innermost part of the lagoon.

The abundance of phytoplankton varies not only between lagoons and seasons but also between stations in the same lagoon. Maximum concentrations are observed at the end of winter/beginning of spring. Total phytoplankton abundance usually ranges between $3x10^4$ to $2x10^6$ cells/l but concentrations of up to $4.4x10^7$ cells/l, belonging mostly to nanoplankton, have been reported under slightly polluted conditions. Such blooms tend to be monospecific and localised.

In the mesozooplankton, densities as low as a few individuals per m^3 to approximately 4 500 indiv/m^3 have been observed. Copepods are the dominant group. In the inner parts of the lagoons the zooplankton consists of brackish water copepod species, accompanied or replaced (depending on the season), by euryhaline species such as larvae of barnacles, molluscs, decapods and polychaetes. In the outer parts, euryhaline species are dominant, accompanied by meroplanktonic larvae and benthic amphipods. Close to the sea, typically marine species enter the lagoons with the currents. Micro-zooplankton in coastal lagoons is represented mostly by ciliates with densities varying from 0.1 to 50 X 10^6 indiv/m^3, according to prevailing environmental conditions, season and distance from the point of communication with the sea.

In general, qualitative and quantitative variability in lagoonal plankton is attributed to variability of environmental conditions, such as salinity and nutrient concentrations, which arise from fresh water input from land and mixing with sea water.

PHYTOBENTHOS

Benthic vegetation in lagoons consists of a small number of species and associations (sensu the ‘Zürich-Montpellier School’). The following five associations are considered most important:

1) Association with *Ruppia cirrhosa* and/or *Ruppia maritima*. *Ruppia* is a cosmopolitan genus, characteristic of many coastal brackish waters and inland salt-water habitats, with enormous tolerance to salinity fluctuations (range ca. 3 to 101 psu).
2) Association with *Zostera noltii* with relatively restricted distribution, mostly in the lagoons of the Amvrakikos Bay (Figure VI.2).

Figure VI.2:
Dense Zostera in an Ionian lagoon.

Table VI.3 *The most important lagoonal species.*

	Plankton	Phytobenthos	Zoobenthos	Fish
Phytoplankton	*Cryptomonas* sp.	*Ceramium diaphanum* (Lightfoot) Roth	*Abra ovata* (Philippi, 1836)	*Anguilla anguilla* Linnaeus, 1758
	Cylindrotheca closterium (Ehrenberg)	*Ceramium flaccidum* (Kützing) Ardissone	Actiniaria	*Aphanius fasciatus* Nardo, 1827
	Goniodoma sphaericum Murray & Whitting, 1899	*Chaetomorpha aerea* (Dillwyn) Kützing	*Armandia cirrosa* (Philippi, 1861)	*Atherina boyeri* Risso, 1810
	Gymnodinium heterostriatum Kofoid & Swezy	*Chondria tenuissima* (Goodenough &Woodward) C. Agardh	*Cerastoderma glaucum* (Poiret, 1789)	*Blenius* sp.
	Oxyrrhis marina Dujardin	*Cladophora liniformis* Kützing	Chironomidae	*Chelon labrosus* Risso, 1826
	Prorocentrum scutellum Schroder	*Cladophora* spp.	*Corophium orientale* Schellenberg 1928	*Dicentrarchus labrax* Linnaeus, 1758
	Protoperidinium depressum (Bailey)	*Cymodocea nodosa* (Ucria) Aschers	*Cyclope neritea* (Linnaeus)	*Diplodus annularis* Linnaeus, 1758
	Rhizisolenia fragilissima Bergon	*Cystoseira barbata* C. Agardh	*Gammarus aequicauda* (Martynov, 1931)	*Diplodus puntazzo* Cetti, 1777
	Rhodomonas sp	*Ectocarpus* sp.	*Hediste diversicolor* (O.F. Müller, 1776)	*Diplodus sargus* Linnaeus, 1758
	Scrippsiella trochoidea (Stein)	*Enteromorpha linza* (Linnaeus) J. Agardh	*Heteromastus filiformis* (Claparede, 1864)	*Diplodus vulgaris* Linnaeus, 1758
Zooplankton	*Acartia clausi* Giesbrecht, 1889	*Enteromorpha* spp.	*Idotea baltica* (Pallas 1772)	*Gobius* sp.
	A. discaudata (Giesbrecht, 1881)	*Gracilaria bursa-pastoris* (Gmelin) Silva	*Iphinoe serrata* (Norman, 1867)	*Knipowitschia caucasica*
	A. latisetosa (Kritschagin, 1873)	*Herposiphonia secunda f. tenella* (C. Agardh) Wynne	*Loripes lacteus* (Linnaeus, 1758)	*Lithognathus mormyrus* Linnaeus, 1758
	Calanipeda aquaedulcis (Kritschagin, 1873)	*Hypnea musciformis* (Wulfen) Lamouroux	*Microdeutopus gryllotalpa* (A. Costa, 1853)	*Liza aurata* Risso, 1826
	Centropages kroyeri Karawaev, 1895	*Polysiphonia elongata* (Hudson) Sprengel	*Mytilaster minimus* (Poli, 1795)	*Liza ramada* Risso, 1826
	Clausocalanus furcatus (Brady, 1883)	*Ruppia cirrhosa* (Petagna) Grande	*Naineris laevigata* (Grube, 1855)	*Liza saliens* Risso, 1810
	Oithona nana Giesbrecht, 1892	*Ruppia maritima* Linnaeus	*Nephtys hombergi* (Savigny, 1820)	*Mugil cephalus* Linnaeus,1758
	O. plumifera Baird, 1843	*Ulva rigida* C. Agardh	Oligochaeta	*Salpa salpa* Linnaeus, 1758
	Paracalanus parvus (Claus, 1863)	*Ulva* sp.	*Streblospio shrubsolii* (Buchanan, 1890)	*Solea vulgaris* Quensel, 1806
	Temora stylifera (Dana, 1849)	*Zostera noltii* Hornem	*Tanais cavolinii* (Milne Edwards, 1828)	*Sparus aurata* Linnaeus, 1758

3) Association with *Cymodocea nodosa*, a characteristic angiosperm of several Hellenic coasts and of saline lagoons. A recent attempt to limit fresh water inflow into the lagoons, as a measure against eutrophication, increased their water salinity and may also have favoured the growth of this species
4) Association with the algae *Cystoseira barbata, Gracilaria bursa-pastoris, Cladophora liniformis* and *Ulva* spp. These species dominate in eutrophicated lagoons or basins within lagoons.
5) Association with *Lamprothamnion papulosum.* The Charophyceae, to which *L. papulosum* belongs, are regarded as a class of the Chlorophyta, despite their highly distinctive thallus and reproductive organs. The association is recorded only in the Amvrakikos Gulf lagoons.

The dominant phytobenthic species are shown in Table VI.3. The diversity and biomass change in space and time. In the Vassova lagoon the diversity tends to decrease and the biomass to increase towards the inner fresh water sources. The diversity is higher during summer in the inner parts and in autumn close to the outlet due to the growth of tropical affinity species. Biomass values are maximal during winter to spring in the inner parts, possibly due to higher loads of nutrients.

MEIOFAUNA

Meiobenthos has been studied only in the Gialova lagoon, where 18 meiofaunal taxa were found with nematodes and copepods being the most abundant. Densities ranged from 17 to over 2 000 individuals per 10 cm^2. The distribution pattern of the meiofaunal community varied both across the lagoon and over the seasons. On the basis of the spatial differences a meiofaunal coenocline [1], correlated with the degree of isolation, was observed, composed of mainly two zones: one defined by the area close to the marine channel and the other the more isolated area in the inner lagoon. The meiofaunal distribution pattern, however, was not clearly correlated to a single environmental variable; apart from purely physical and chemical characteristics it was also associated with food supply.

ZOOBENTHOS

Macrozoobenthos is the ecosystem component most studied in Hellenic lagoons. The most abundant species are shown in Table VI.3.

Four main groups of benthic invertebrates are found in coastal brackish water lagoons, depending on their hydrologic and trophic status: i) *fresh water* species, represented by chironomid larvae and oligochaetes, found in areas remote from the sea with increased fresh water input; ii) *euryhaline brackish water* species, which are the most widely distributed and highly abundant species; iii) *marine* species preferring shallow sheltered areas; and iv) *opportunistic* species, commonly found in abundance in organically enriched areas. Most species are common to all lagoons. What differs is their relative abundance, which varies according to season and the life cycle of the dominant species.

It is worth mentioning the dominance of the mud snail *Ventrosia maritima*, found exclusively in extremely isolated areas of the Evros Delta. This mud snail was only known from the Black Sea. However, utilising DNA sequencing and phylogenetic analyses, the occurrence of this species was recently ascertained in the Evros Delta. *Ventrosia maritima* is a typical lagoonal species. To our knowledge, the life cycle, population dynamics and productivity of this species have not been described yet.

The most important variable shaping species composition and macrobenthic community structure is the degree of communication with the sea, or *confinement*, described by GUELORGET & PERTHUISOT (1992) as the time required for a lagoon to renew its marine elements. Six zones, as described in the model, have been found in Hellenic lagoons: <u>Zone I</u>, which is a continuation of the sea, with strictly marine species; <u>Zone II</u>, where the more stenohaline marine species are missing; <u>Zone III</u>, with mixed species; <u>Zone IV</u>, with strictly brackish water species; <u>Zone V</u> with only vagile fauna and freshwater (hypohaline) or evaporitic (hyperhaline) species and finally; <u>Zone VI</u>, which shows almost total colonisation of substratum by Cyanobacteria. Some or all of the zones are present in each lagoon, as shown in Figure VI.3 for the lagoon Gialova. The limits of the zones may show seasonal shifts

[1] Definition coenocline: a figure representing the distributions of all species as a function of evnironmental gradients.

indicating the dynamic character of the lagoonal environment.

The degree of confinement affects community diversity. There is a negative correlation between confinement and diversity (Figure VI.4). The lowest diversity is observed in enclosed lagoons, most isolated from the marine environment, while in lagoons with an important marine element and good water circulation, diversity is high. Such differences in diversity may be observed in the same lagoon, where the inner parts show the lowest diversity and the canals of communication with the sea the highest.

FISH FAUNA

The most common and abundant fish species are shown in Table VI.3. Lagoonal fish species can be divided in three different categories: i) *typical lagoonal species*, which complete their whole life cycle in lagoons, occupying the innermost part of the lagoonal systems where salinity, temperature, dissolved oxygen as well as other environmental variables present a severe fluctuation; ii) *migratory marine/estuarine species*, which reproduce in the sea, but which spend a period of their life in brackish waters and are found in the inner parts of the

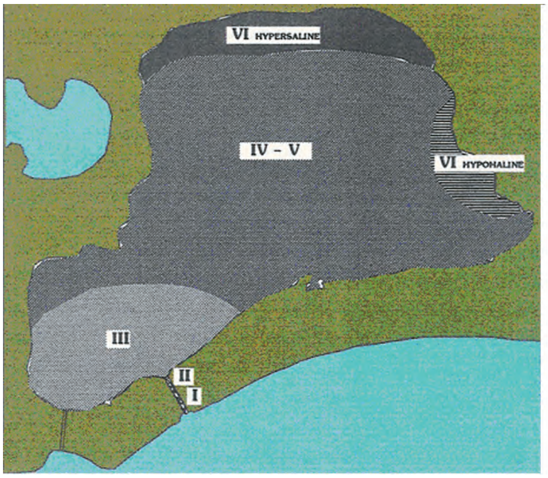


Figure VI.3:
Biological zonation in the Gialova lagoon according to the scheme proposed by GUELORGET & PERTHUISOT (1992).

Source: *DOUNAS & KOUTSOUBAS, 1996.*

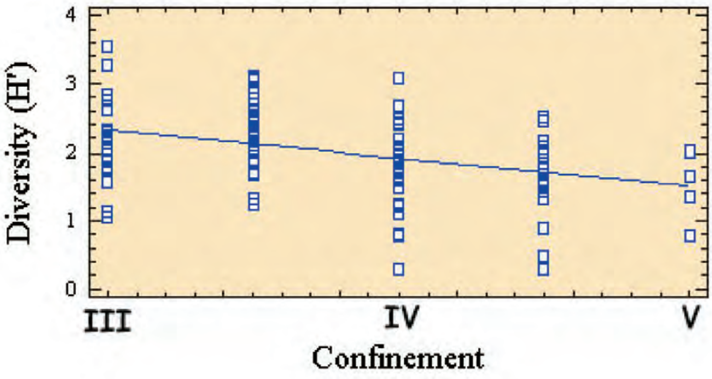


Figure VI.4:
Regression of diversity against confinement (based on data from the lagoons of Amvrakikos, Mesolongi, Papas, Vivari and Gialova).

Source: *REIZOPOULOU & NICOLAIDOU, 2004.*

lagoons, but only during the most stable period from spring to autumn; and iii) *marine species* which are normally distributed in the sea and are occasionally or accidentally found in the lagoons, in the narrow zone influenced by the sea.

In accordance with other biotic components of the lagoonal system, fish fauna is characterised by spatial and temporal variability, both in terms of numbers of species and individuals. There is a general tendency of the most rich fish fauna, both in terms of species numbers and density, to exist from spring to autumn, while during the winter very few species and low densities are observed.

Most lagoons in Hellas are used for the extensive culture of various fish species, the majority of which belong to the migratory marine/estuarine species. Mean annual production varies significantly depending on the size of the lagoon while differences are also observed in the fish catch composition.

MODELLING

The European Regional Seas Ecosystem Model (ERSEM), initially designed for the open sea, has been usefully applied to the Gialova lagoon with minimum modifications. Model results depicting the seasonal variation of nutrients and Chl-a in the water column, as well as three benthic functional groups (suspension feeders, deposit feeders and benthic carnivores), have been validated with *in situ* data. The modelled pelagic ecosystem exhibits a microbial food web, characterised by competition for nutrients between bacteria and phytoplankton, which is broadly in agreement with the observations made. The heterotrophic biomass is larger than the autotrophic biomass and there is a strong benthic-pelagic coupling in the model, as would be expected in a shallow system rich in detrital material. The seasonal variations in the benthic flux of nutrients are tightly coupled to the phytoplankton nutrient demand and hence to the supply of detritus to the sediments. The benthic recycling of nutrients (especially silicate) helps to maintain the modelled diatom population, which is indicated by the higher diatom biomass in the near-bed layer. The likely effect of a technical intervention (river input) increasing the fresh water nutrient inputs on the lagoonal ecosystem functioning has also been investigated. Detailed annual carbon fluxes and benthic fauna biomasses have been calculated before and after the river input, and importance of external physical/chemical forcing on the pelagic system and its subsequent effect on the benthic system has also been investigated. Model experiments indicate the shift of the ecosystem from nitrate limitation to predator control with external inputs. Model experiments also show a significant increase in the amount of carbon entering the benthic system through the activity of filter feeders when river inputs are implemented. The sensitivity analysis performed on model responses to different river nutrient fluxes and silt concentrations has highlighted the potential utility of a model as an operational tool to support environmental management decisions.

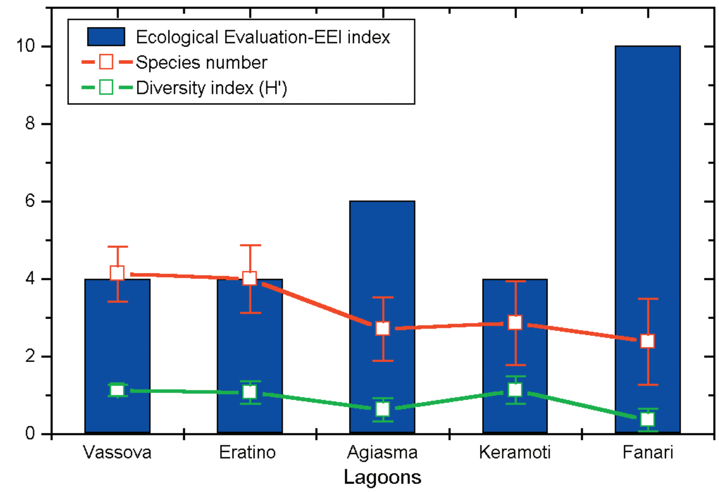
POLLUTION

Lagoons are nutrient rich areas as a result of input of nutrients by rivers and recycling between sediment and water column facilitated by their shallowness. A nutrient excess and hydrological change, often accelerated by human intervention, in the lagoons, result in a non-linear and self-accelerating chain reaction, commonly called eutrophication. It starts with an increase in growth (organic production) and a shift in dominance of primary producers from angiosperms to opportunistic seaweeds, and culminates in a *dystrophic crisis* with extensive algal blooms, severe anoxia and mass mortalities of both fish and invertebrate fauna. Such events are not uncommon in some Hellenic lagoons such as Papas, Aetoliko, Gialova and Vassova where some areas become completely defaunated, especially during summer. The sedentary infauna is affected more than the vagile organisms, such as Crustacea and Fish, which are able to migrate. Recovery is generally rapid, as organisms soon recolonise the affected areas. The Papas lagoon, for example, which was affected by a summer dystrophic crisis with extensive mortality of fish and benthic invertebrates, recovered the same autumn. This was also true for Gialova.

The degree of pollution in Hellenic lagoons has been assessed by an array of methods, including Abundance-Biomass-Comparison (ABC) curves and plotting of Geometric Abundance Classes, which are widely used for pollution assessment in the marine environment. However, due to the naturally stressed condition of the lagoons, these methods were ineffective as was the application of the Shannon-Wiener diversity index. Thus, two new indices were proposed, one is the Ecological Evaluation Index (EEI), based on macrophytes, algae and angiosperms. The other, the Index of Size Distribution (ISD) is based on the size distribution of macrobenthic animals.

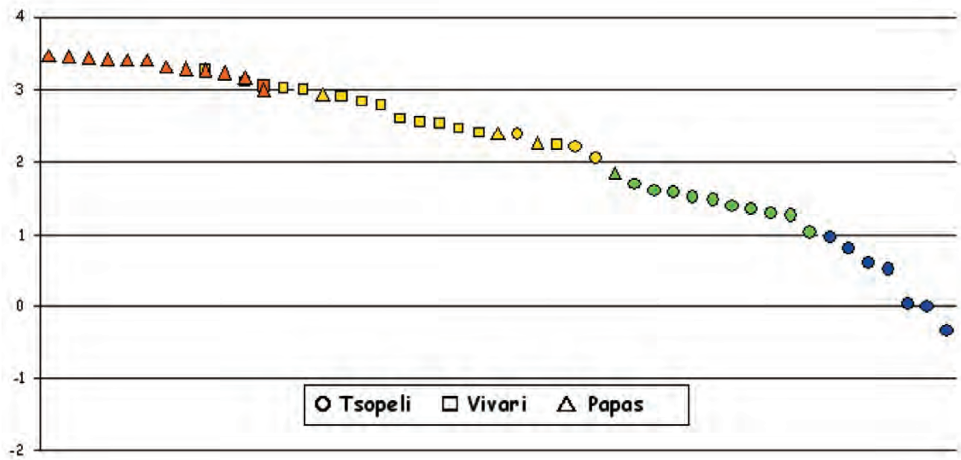
The EEI is described in detail in Chapter VIII. Its application in five Hellenic lagoons and the comparison with diversity indices, considered inappropriate for ecological assessment, is shown in Figure VI.5.

The ISD is based on the observation that with increasing organic load the community size structure changes. Due to the dominance of small size opportunistic species and the decline of large-bodied specimens (mainly suspension-feeders and carnivores), smaller and fewer size classes are present, thus, size class distribution is skewed towards the smaller size classes. The value of skewness of the curve is used as a measure of environmental quality. It has the advantage of a good discrimination power and not requiring a high taxonomic expertise. Application of the index in three Hellenic lagoons is shown in Figure VI.6.



Source: *ORFANIDIS et al., 2001.*

Figure VI.5:
Ecological Evaluation Index (EEI) in comparison to diversity indices in five Hellenic lagoons. High EEI values correspond to the less affected lagoons. Line bars indicate 95% confidence intervals.



Source: *REIZOPOULOU & NICOLAIDOU, 2005.*

Figure VI.6:
ISD (Index of Size Distribution) in three Hellenic lagoons. Higher values correspond to the most disturbed lagoon, Papas and smaller to the less affected, Tsopeli.

CONCLUSIONS

The research carried out so far in Hellenic lagoons confirms the variability of the environment, demonstrated also for other coastal lagoons in the Mediterranean. Differences exist not only among lagoons but also within the same lagoon, both in space and time. The degree of communication with the sea affects most of the other environmental variables, playing a prominent role in shaping the biological communities. Inflow of fresh water is also very important in the differentiation of biota. However, neither of the above has been directly quantified so far. The zoning of confinement is based on the end result the species distribution rather than the causative factor the water circulation and exchange. An independent evaluation of confinement, based on physical predictors rather than on the fauna, might provide a better understanding of its role. The input of fresh water and the contributed organic matter and nutrients of natural or human origin, would give a clearer picture of the terrestrial influence.

Finally, it is demonstrated that variability between and within lagoons concerns mostly the dominance of species and not the presence of different sets of species. Changes in the dominance of species could be caused not only by natural and/or anthropogenic variability in the physical environment, but also by biological interactions such as competition and predation. Giving more emphasis to the autecology of the dominant species would give a better insight into the dynamics of the lagoonal communities.

VI.2. MEIOFAUNA IN THE AEGEAN SEA

Meiofauna is a term derived from the Hellenic word meioς meaning smaller. It is used to describe organisms, which are smaller than what has been defined as the lower size limit for macrofauna, which are those organisms retained in a 1 mm sieve. Although there is still some controversy about the definition of meiofauna, today the term is used to refer to those small benthic invertebrates that pass through a 500 μm sieve and are retained in a 42 μm sieve. The study of meiofaunal ecology has become a basic component of benthic research.

Concerning the Mediterranean as a whole, knowledge of meiobenthos is still very scarce. Most studies have been undertaken in the northwestern basin whereas in the eastern basin and particularly in the Aegean Sea, meiofaunal research has been significantly neglected over the past decades. Although taxonomic studies of marine meiobenthic organisms were already going on in the Mediterranean since the middle of the 19th century, the first meiobenthic quantitative data in the eastern Mediterranean were those of DINET (1976) from the North Aegean Sea Trench. Since then, several meiobenthic studies have been carried out in the Aegean Sea across three main axes: a) the distribution and abundance of meiobenthos of sandy beaches, the continental shelf and the deep-sea, b) pollution monitoring studies, and c) meiofauna in specific environments (e.g. hydrothermal vents).

The aim of this document is to summarise all the current published information of meiofauna in the Aegean Sea. The available published or unpublished information on the meiofauna of the Hellenic Seas remains scattered in the literature and no attempt has been made to bring it together in order not only to provide an arrangement of the existing information on meiobenthic studies, but also to allow a composite picture to be put together on the biogeography and biodiversity of the meiobenthic communities of the eastern Mediterranean.

Bathymetric trends

Studies on the abundance and distribution of sandy beach meiofauna have been conducted in eleven different littoral beaches in Hellas, four on the island of Kriti and seven around Attiki (Figure VI.7). Although all beaches investigated

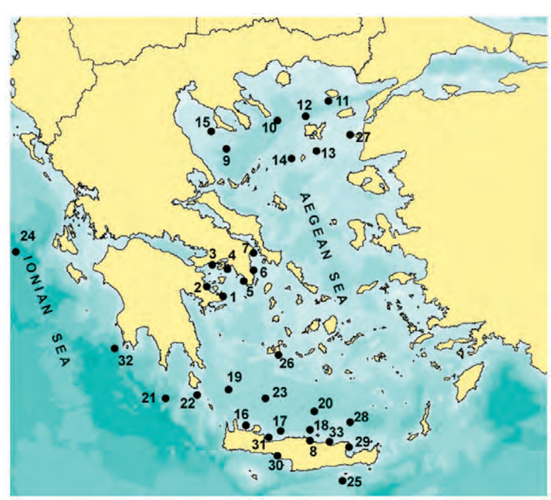


Figure VI.7:
Map of the Hellenic Seas showing the areas of investigations. Numbering of areas corresponds to that of Table VI.4.

were near centres of urbanisation and industrialisation, all of these studies remain unpublished. The maximum meiofauna densities were found near the domestic and industrial sewage outfalls of Athens and Irakleio (Areas 3, 4 and 8 respectively in (Table VI.4). These high meiofaunal densities are among the highest densities reported for Mediterranean beaches (SOYER, 1985). High population densities were directly associated with the effect of organic pollution as indicated by the absence of certain groups, the low densities of some other groups as well as the deeper distribution of nematodes in the sediment, several species of which are known to survive in highly reducing sediments. The meiofaunal

Table VI.4: *Summary information on standing stocks of metazoan meiobenthos in the Hellenic Seas (continued)*

Area on Map	Area	No of stations	Depth Range (m)	Sampling Date	No. of Sampling Times	Mesh (μm)	Total Abundances ind.10 cm^{-2}	Source
1	Methana-Galatas beach	4	0	1975	1	45	?	ELEFTHERIOU (1979)
2	Epidavros beach	2	0	1975	1	45	93	ELEFTHERIOU (1979)
3	Keratsini	3	0	1975	1	45	103-3432	ELEFTHERIOU (1979)
3	Elefsis sublittoral	3	4-5	1989	1	45	225-2266	ZACHARIADI *et al.*, 1990
4	Akti Themistokleous	?	0	1975	1	45	1744	ELEFTHERIOU (1979)
5	Anavissos-Sounio	3	0	1975	1	45	?	ELEFTHERIOU (1979)
6	Loutsa beach	3	0	1975	1	45	470-1017	ELEFTHERIOU (1979)
7	Marathonas	3	0	1975	1	45	593	ELEFTHERIOU (1979)
8	Karteros-Tobruk	5	0	1992	1	45	180-886	LAMPADARIOU, 1993
8	Linoperamata	3	0	1992	1	45	282-3636	LAMPADARIOU, 1993
8	Irakleio Harbour	9	5-22	1992	1	45	273-9342	PAPADOPOULOU *et al.*, 1998
9	Sporades basin	5	130-1209	1972	1	50	69-488	DINET, 1976
9	Sporades basin	5	112-1202	1972	1	?	103-812	CHARDY *et al.*, 1973
10	Chalkidiki	3	236-1308	1972	1	?	166-622	CHARDY *et al.*, 1973
10	Chalkidiki	1	975	1997-1998	3	32	221-882	MATER Final report
11	Samothraki	1	880	1972	1	50	378-415	DINET, 1976
12	Limnos Basin	4	138-1290	1997-1998	3	32	169-1584	LAMPADARIOU & TSELEPIDES, 2000a
13	Limnos Island	1	1150	1997-1998	2	32	491-1076	LAMPADARIOU & TSELEPIDES, 2000b
14	Sporades	1	805	1997	1	32	169-171	LAMPADARIOU & TSELEPIDES, 2000b
15	Thermaikos Gulf	5	100-1000	1987	1	45	39-401	ROIDOU & ELEFTHERIOU, 1989
15	Thermaikos Gulf	8	?	1992	1	45	37-839	ZACHARIADI & PANAGIOTIDIS, 1993
16	Chania Gulf	6	30-200	1987	1	45	127-319	ROIDOU & ELEFTHERIOU, 1989
17	Rethymnon Gulf	5	30-200	1987	1	45	122-392	ROIDOU & ELEFTHERIOU, 1989
18	Irakleio Gulf	5	30-1000	1987	1	45	16-579	ROIDOU & ELEFTHERIOU, 1989
18	Irakleio Gulf	4	20-190	1989-1990	12	45	24-1584	LAMPADARIOU, 2001
18	Irakleio Gulf	4	70-160	1989-1990	4	45	165-584	SFS Final report
19	Cretan Sea	2	900-1190	1997-1998	3	32	216-406	LAMPADARIOU & TSELEPIDES, 2000a
19	Cretan Sea	3	533-1147	1989	1	45	68-130	DANOVARO *et al.*, 1995a
20	Cretan Sea	3	1290-1720	1997-1998	3	32	128-199	LAMPADARIOU & TSELEPIDES, 2000a
20	Cretan Sea	3	1078-1840	1989	1	45	66-257	DANOVARO *et al.*, 1995a
20	Cretan Sea	2	934-989	1989	1	37	105-137	DANOVARO *et al.*, 1995b
21	Hellenic Trench	1	4617	1993	1	32	9-82	TSELEPIDES & LAMPADARIOU, 2004
21	Cretan Sea	3	946-2401	1989	1	45	4-33	DANOVARO *et al.*, 1995a

(continued)

Area on Map	Area	No of stations	Depth Range (m)	Sampling Date	No. of Sampling Times	Mesh (µm)	Total Abundances ind.10 cm^{-2}	Source
22	Cretan Sea	4	550-1215	1989	1	45	107-286	DANOVARO *et al.*, 1995a
22	Ionian Sea	1	984	1989	1	37	199	DANOVARO *et al.*, 1995b
23	Cretan Sea	2	915-1053	1989	1	45	66-91	DANOVARO *et al.*, 1995a
24	Ionian Sea	1	2942	1993	1	32	12-29	TSELEPIDES & LAMPADARIOU, 2004
25	Plinny Trench	2	1354-4260	1993	1	32	64-217	TSELEPIDES & LAMPADARIOU, 2004
26	Milos Island	11	5-10	1992	1	63	0-500	THIERMANN *et al.*, 1994
26	Milos Island	12	10-14	1993-1994	1	63	887-1075	THIERMANN *et al.*, 1997
27	Limnos Island	15	?	?	1	?	550	KISSELEVA, 1961
28	Cretan Sea	1	2280	1997	1	32	24-28	LAMPADARIOU & TSELEPIDES, 2000a
29	Pachia Ammos beach	1	0	1989	1	None	Qualitative	HUMMON, 1990
30	Plakias beach	1	0	1989	1	None	Qualitative	HUMMON, 1990
31	Georgioupolis beach	1	0	1989	1	None	Qualitative	HUMMON, 1990
32	Hellenic Trench	1	3745	1993	1	32	38-141	TSELEPIDES & LAMPADARIOU, 2004
33	Bay of Malia	11	10-70	1992	1	45	368-2485	BUCHHOLZ & LAMPADARIOU, 2002

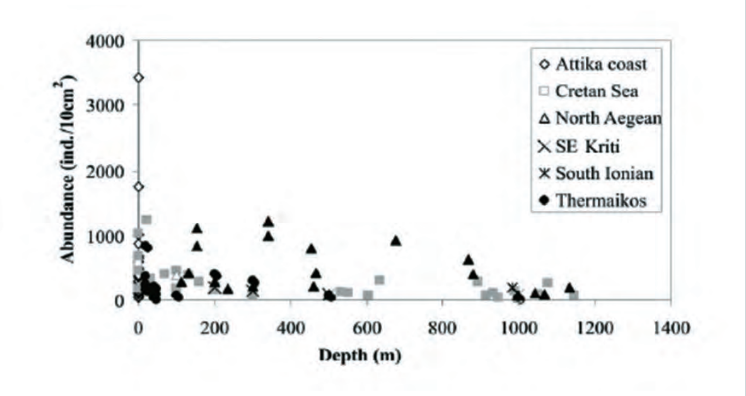


Figure VI.8:
A comparison of meiofaunal densities in Hellenic Seas.

Table VI.5: *List of meiobenthic studies at lower taxonomic levels in the Aegean Sea.*

Taxon studied	Taxonomic level	No. of species/ genera found	Abundant species
Nematoda	Species	155	*Richtersia* sp.
Foraminifera	Species	>56	*Nodellum membranacea*
Gastrotricha	Species	30	*Heteroxenotrichula squamosa*
			Procamacolaimus
Nematoda	Genus	80	*Epsilonema*
Nematoda	Species	280	*Richtersia coomansi*
Foraminifera	Genus	>30	*Cyartonema n.* sp.
			Epistominella
Nematoda	Genus	33	*Enoplolaimus*
Copepoda	Species	12	*Odondophora*
Nematoda	Species	44	*Psammotopa phyllosetosa*
			Chromadora nudicapitata
			Chromadorella membranata
Copepoda	Species	14	*Arenopontia nesaie*
			Psammotopa phyllosetosa

densities in all other areas (Areas 1, 2, 5-7; Table VI.4) were significantly lower and similar to beach densities reported from other areas of the Mediterranean (COVAZZI HARRIGUE *et al.*, 2000).

In general, metazoan meiofauna tends to decrease in abundance with increasing depth, a rule that is also valid for the Mediterranean (DANOVARO & FABIANO, 1995). This tendency however, does not hold for small scale geographic areas as illustrated in Figure VI.8, which may show different and conflicting patterns of density gradients. For example, LAMPADARIOU & TSELEPIDES (2000a) reported that in the north Aegean Sea (Area 12), meiofaunal densities increased with increasing depth, a result which they attributed to the increased primary production of the north Aegean.

In the Aegean Sea, the first reports on the distribution of meiobenthos from sub-littoral areas concluded that meiofauna was virtually absent from certain depths in unspecified areas of the Aegean. However, these data are not reliable because of the different and not quantitative sampling methodology used. Indeed, all the following studies on the distribution of meiofauna in the Aegean Sea reported the existence of various meiofaunal taxa which occurred occasionally in relatively high densities. Compared to the other parts of the Mediterranean, the densities found in the north Aegean Sea were higher than those reported from the northwestern Mediterranean basin at comparable depths (SOYER, 1985, De BOVEE *et al.*, 1990), a result that has been mainly attributed to the nutrient-rich waters originating from the Black Sea and flowing through the Sea of Marmara into the Aegean basin. On the other hand, densities reported from the south Aegean and Ionian seas were much lower, compared to other areas of the Mediterranean, at the lower slope and bathyal areas and extremely low at the deeper parts of the basins (TSELEPIDES & LAMPADARIOU, 2004). As a general rule, the densities found in bathyal sediment and the deeper parts of the south Aegean were among the lowest reported for the whole Mediterranean, a feature that has been mainly attributed to the low coastal productivity of this area (DANOVARO & FABIANO, 1995).

Community structure

There have been few studies (Table VI.5) of meiobenthos at the lower taxonomic levels (family, genus and species). Usually, nematodes and copepods were investigated (Figure VI.9), since these two groups are the dominant groups in most of the cases. Some sparse information is also available for marine Gastrotricha whereas more recently, studies on Foraminifera have also been undertaken. In most of these studies, the distribution of the dominant species was mainly influenced by food availability expressed either as carbon mineralisation rates or the concentration of

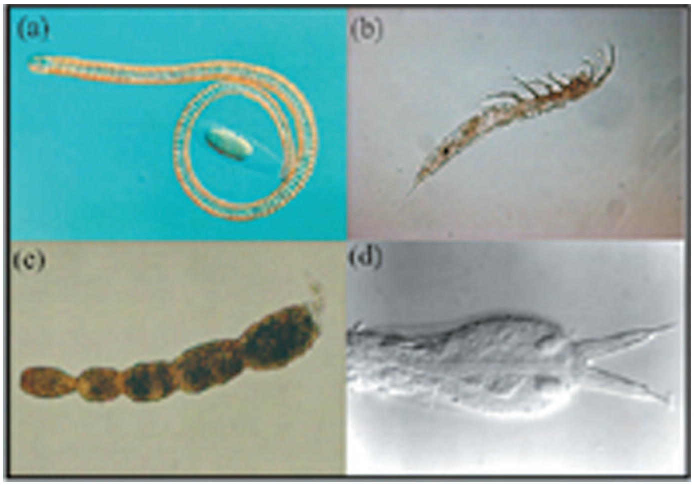


Figure VI.9:
Some abundant meiobenthic species found in the Hellenic Seas. (a) a free living marine nematode, Pselionema sp (Photo T. BUCHHOLTZ); (b) a harpacticoid copepod, Arenopontia acanthia (Photo K. SEVASTOU); (c) a soft cell benthic foraminiferan, Nodellum membranacea (Photo E. HATZIYANNI); (d) a marine gastrotrich, Heteroxenotrichula squamosa (Photo: W.HUMMON).

chlorophyll a in the sediment or a more complex system of abiotic factors, such as the high wave energy in beach areas during winter, which negatively affected abundances at the surface of the sediment.

Pollution studies

A small number of pollution studies, which consider the use of meiofauna as potential indicators of anthropogenic disturbance have also been undertaken. These studies concern mostly domestic sewage discharges and pollution in harbours or experimental studies using laboratory and field microscosms. The general conclusion of these studies is that there is a general decrease in the number of species or taxa(s) with increasing organic loading, although an increase in the abundances can be observed (Figure VI.10). A further wide application of such experiments (BOYD *et al.*, 1989) using meiofaunal organisms, would reveal important pollution gradients in the large island archipelago and could promote measures for the management and protection of the marine environment.

Selected biotopes

Meiobenthic communities have also been studied near shallow hydrothermal vents (10 m depth) in a sandy bay on the south coast of Milos (Area 26) (THIERMANN *et al.,* 1994). Sediment temperatures within the active vent area ranged from 55 to 97˚ C and sulphide concentrations were about 1000 μM. The results showed that meiobenthic life was present only at a certain distance from the emissions at moderate temperatures and sulphide concentrations.

CONCLUSIONS

Meiofaunal studies have only recently been accounted with their proper status as they have only recently been recognised as a valid intermediate between the macrofauna and the microfauna. This delay is even more

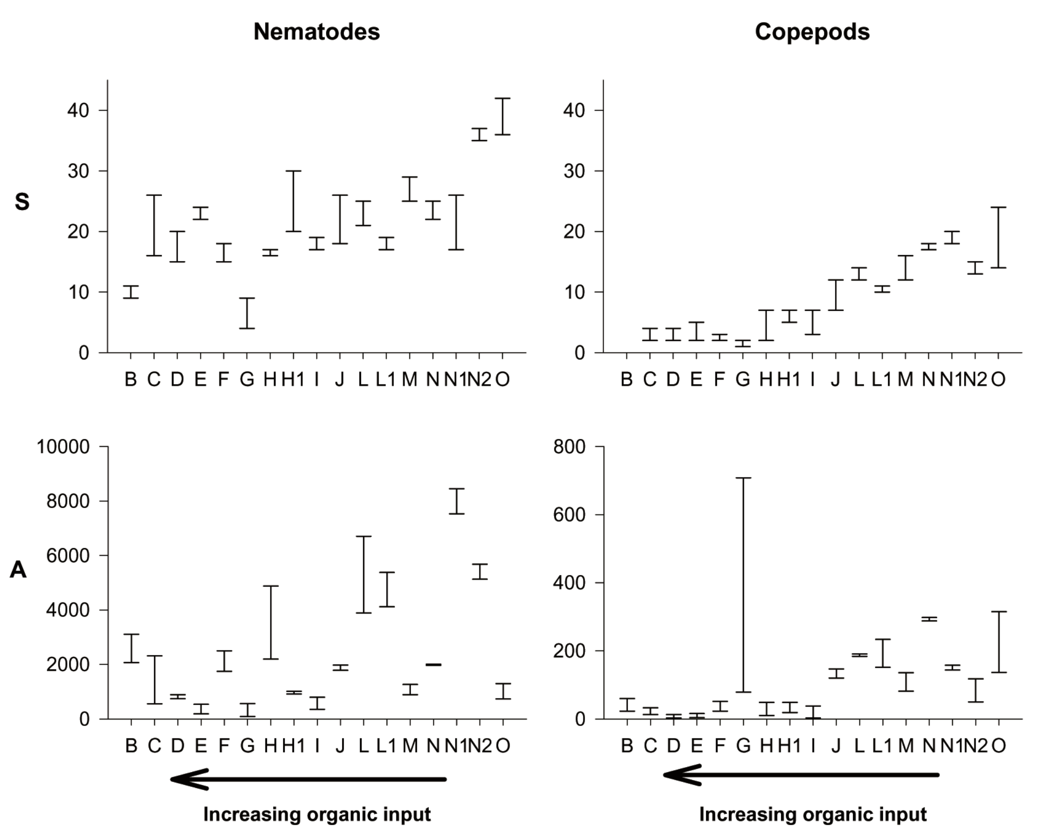


Figure VI.10: *Meiofaunal reaction in relation to an increase in organic pollution in Irakleio harbour (Modified LAMPADARIOU et al., 1997). S: number of species; A: abundance.*

pronounced in the Mediterranean where, apart from the earlier but sparse taxonomic studies, there was a lack of any significant investigation on the position of the meiofauna in the marine ecosystem. The last decade has seen an important development in meiofaunal research spreading to the eastern Mediterranean. These studies, scattered around Kriti Island and the Aegean Sea and concentrating in the deep-sea, have revealed existing trends which confirmed the universality of the ecological principles which determine the structure and dynamics of the meiofaunal populations. The identification and quantification of the main parameters were recognised and their influence on the diversity, distribution and abundance of these populations along well recognised gradients were also confirmed from these studies. Thus the decrease in the abundance and biomass of the meiofaunal populations in the eastern Mediterranean along the main gradient axis has been well documented, as well as the predictable and similar decline of the same indices with depth. However, these were counterbalanced by the surprising discovery of a high meiofaunal biodiversity, especially of the nematodes, several species of which were new to science. On the other hand, distortion of the existing gradients was expressed by the high biotic indices in the deeper sediments especially in the Mediterranean trenches where trapped food becomes a factor of paramount importance. However, beyond these relations these studies touched on important and interesting issues concerning the meiofauna of the Hellenic Seas and of the eastern Mediterranean. Concomitantly they posed important questions on the structure and function of the meiofaunal communities in a strictly oligotrophic system heavily influenced by extremes of temperature and salinity.

VI.3. BENTHIC MACROPHYTES: MAIN TRENDS IN DIVERSITY AND DISTRIBUTION

Marine benthic macrophytes comprise evolutionary primitive plants known as seaweeds or marine macroalgae (Figure VI.11) and evolutionary advanced flowering plants known as seagrasses or marine angiosperms (Figure VI.12). Seaweeds are numerous and quite diverse organisms belonging to the divisions red algae (Rhodophyta), brown algae (Phaeophyta or Ochrophyta) and green algae (Chlorophyta). Seagrasses are neither numerous nor diverse, belonging to the division Tracheophyta, class Magnoliophyta. Despite the obvious evolutionary and morphological differences, seaweeds and seagrasses coexist in many coastal benthic habitats. They live from the sea surface to the deeper limit of the euphotic zone, where adequate light for growth can penetrate. Whereas seaweed attaches mostly to hard substrata (rocks, boulder, shells, other aquatic animal or plants), seagrasses root in soft substrata (sand, mud). Several well-developed communities can be differentiated as a function of water and sediment properties, and hydrodynamism.

Rocky substrate flora of shallow Hellenic embayment and islands is relatively well known. Although several taxonomic papers have been published, many records are still problematic since morphological descriptions and voucher material is limited. The total macrophytes of the Hellenic coasts are estimated at about 550 taxa (Table VI.6).

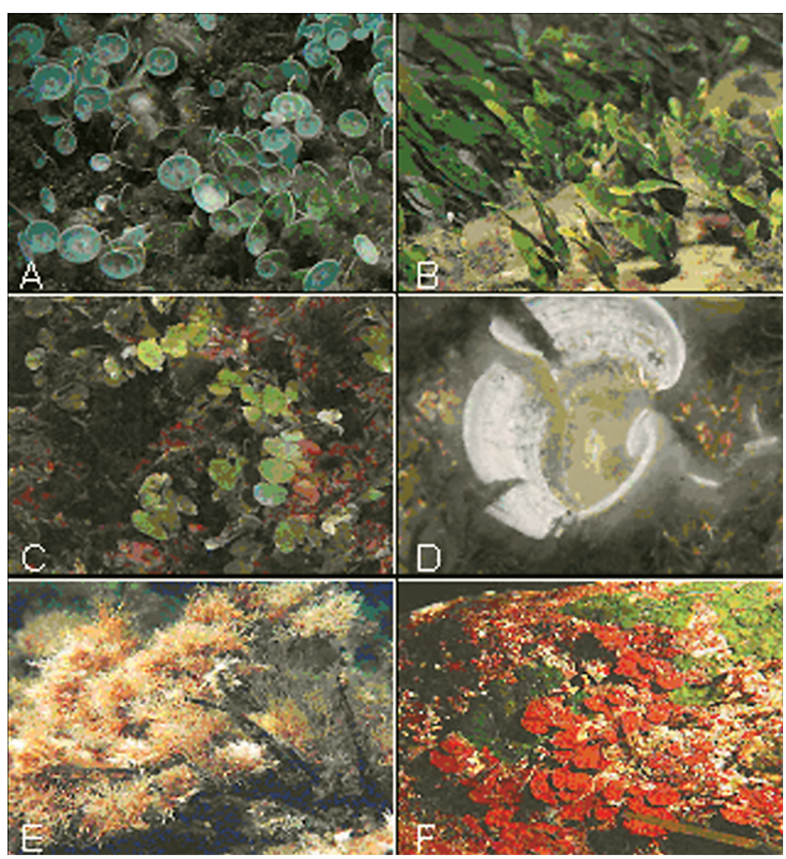
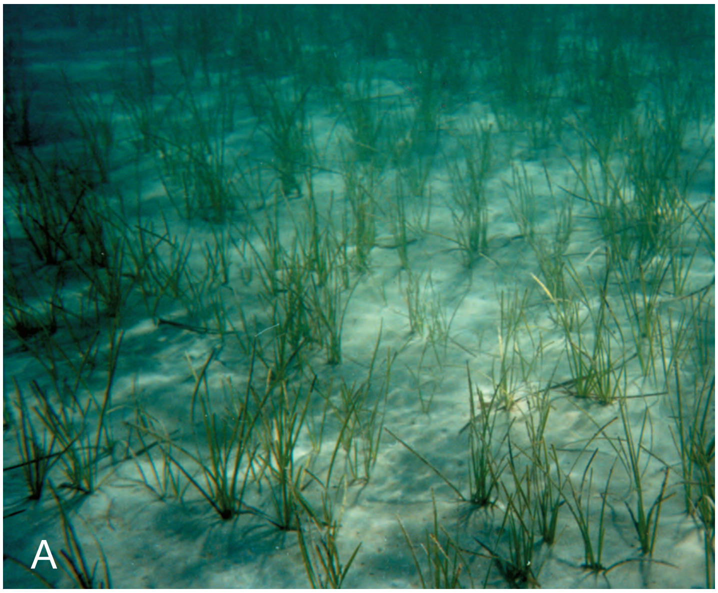


Figure VI.11:
Seaweeds are multicellular differently coloured algae. Underwater views: A. Acetabularia acetabulum, B. Caulerpa prolifera, C.Halimeda tuna, D. Padina pavonica, E. Cystoseira sp., F. Peyssonnelia sp.

Photo: *M. PANTAZI.*

Table VI.6 *Macroalgal diversity (species number) at different Hellenic coasts.*

Geographic area	Red algae	Brown algae	Green algae	Total number	Source
Northern Aegean coasts	94	35	37	166	HARITONIDIS & TSEKOS (1975)
Thermaikos Gulf, Aegean Sea	68	29	24	121	HARITONIDIS (1978)
Sithonia coasts, Aegean Sea	180	58	33	271	ATHANASIADIS (1987)
Saronikos Gulf, Aegean Sea	119	37	41	197	DIAPOULIS & HARITONIDIS (1987)
Milos Island, Aegean Sea	128	30	32	190	LAZARIDOU (1994)
Maliakos Gulf, Aegean Sea	98	40	47	186	CHRYSSOVERGIS & PANAYOTIDIS (1995)
Aegean Sea (review)	265	89	74	428	ATHANASIADIS (1987)
Ionian coasts	94	39	30	163	TSEKOS & HARITONIDIS (1977)
Kefallonia Island, Ionian Sea	165	47	53	265	SCHNETTER & SCHNETTER (1981)



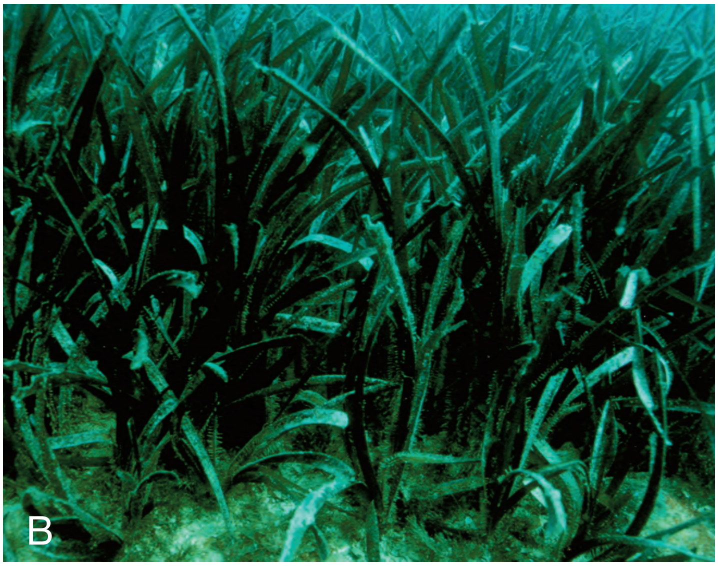


Photo: *P. PANAYOTIDIS.*

Figure VI.12:
marine flowering plants. Underwater views:
A. Sandy bottom covered with Cymodocea nodosa meadow at Schinias coasts (south Evvoikos),
B. Posidonia oceanica meadow in the Saronikos Gulf.

Most of the species can be found near the surface (ca. 10-45 species/0.04 m^2) forming a distinct vertical zoning pattern (Figure VI.13). Irregular exposure to air due to water level fluctuations sets back the succession of upper midlittoral macroalgal communities and favour short-lived cyanophytes and the genera of *Bangia, Porphyra* and *Cladophora*. In the lower midlittoral zone long-lived species of the genera *Lithophyllum* and *Corallina* can be found. In the upper infralittoral zone where plants are always submerged and light is abundant (ca. 1200 μmol photons m^{-2} s^{-1} at 1 m depth in summer on Makedonian coasts) dense macroalgal communities develop with the most characteristic being the canopy forming and climax species of the genus *Cystoseira*. In the lower infralittoral where light is scarce, sciaphilic genera *Flabellia* and *Peyssonnelia* can be dominant.

Within the main taxonomical seaweed groups the red algae dominate by means of diversity (species number) followed by brown algae and green algae (Figure VI.14a). In a typical shallow, down to 3 m depth pristine coast, the brown algae, mainly due to the perennial *Cystoseira* genus, often dominate by means of abundance (coverage or biomass) followed by red algae and green algae (Figure VI.14b).

Temporal variability of macroalgal community is more intense in the midlittoral zone where seaweed abundance and diversity picks up at the end of winter to spring due to high water level and nutrient concentrations. Infralittoral communities seem to

		Deep moderately exposed	Shallow sheltered
Supralittoral		Blue-green algae (Cyanobacteria) Lichens *(Verrucaria)* Gasteropods *(Littorina)* Isopods *(Ligia)* *EUNIS code B3.1 (http://eunis.eea.eu.int/habitats.jsp)*	
Midlittoral	upper	Filamentous & foliose red algae *(Bangia, Porphyra)* Filamentous green algae *(Cladophora)* *Barnacles (Chthamalus)* Limpets *(Patella)*	Filamentous red algae *(Porphyra)* Filamentous & foliose green algae *(Cladophora, Ulva)* Barnacles *(Chthamalus)* Limpets *(Patella)*
	lower	Calcareous red algae *(Corallina, Lithophyllum)* Limpets *(Patella)* Bivalves *(Mytilus)* *EUNIS code A1.23*	Coarsely branched red algae *(Gelidium, Gigartina, Laurencia)* Filamentous red algae *(Polysiphonia)* Limpets *(Patella)* *EUNIS code A1.34*
Infralittoral	upper	Calcareous red algae *(Corallina, Lithophyllum, Jania)* Thick leathery brown algae *(Cystoseira, Sargassum, Padina)* Coarsely branched red algae *(Gigartina, Laurencia)* Filamentous brown algae *(Stypocaulon, Sphacelaria)* Sea urchins *(Paracentrotus & Arbacia)* *EUNIS code A3.23*	Thick leathery brown algae *(Cystoseira, Sargassum, Padina)* Foliose brown algae *(Dictyota)* Filamentous red algae *(Falkenbergia, Polysiphonia)* Seagrasses *(Cymodocea, Zostera, Halophila)* Sea urchins *(Paracentrotus & Arbacia)* *EUNIS codes A3.33, A5.53*
	lower	Calcareous green algae *(Halimeda, Acetabularia, Flabellia)* Calcareous red algae *(Peyssonnelia)* *EUNIS code A3.23*	Seagrasses (*Cymodocea, Zostera, Halophila, Posidonia)* *Coarsely branched green algae* *(Caulerpa)* *EUNIS code A5.53*

Source: *Based on the work of HARITONIDIS, DIAPOULIS, LAZARIDOU & CHRYSSOVERGIS.*

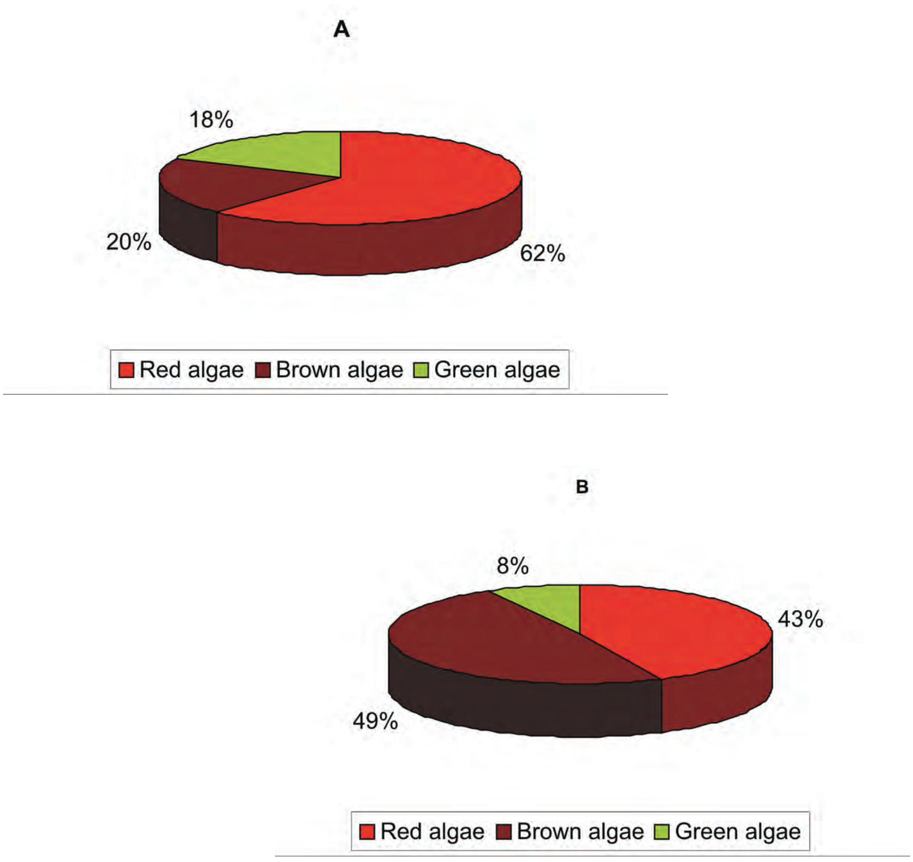
Figure VI.13: *Benthic macrophytic zoning pattern in two water body types: A. Hard deep moderately exposed, B. Hard shallow sheltered.*

be more seasonally stable than midlittoral, with the abundance peak in spring when nutrients and light are abundant, whereas the diversity peak is in autumn when species of tropical affinity, e.g. *Acanthophora najadiformis*, are gained. Deep-water communities peak may occur in summer when incoming light is by ca. 4-fold higher than in winter.

As far as the seagrasses are concerned, the species *Posidonia oceanica* and *Cymodocea nodosa* are widespread, especially in the north Aegean, whereas the species *Zostera noltii* and *Halophila stipulacea* are restricted to specific areas. *Posidonia oceanica* is forming extensive and high productive meadows, where dry photosynthetic biomass and leaf area index peaked in summer (in average 800 g/m^2 and 18 g/m^2 at 5 m depth of the Saronikos Gulf; 500 g/m^2 and 10 g/m^2 at 14±2 m depth of the Strymonikos Gulf) regulated mainly by seasonal changes in light and temperature. The role of nutrient availability and water movement in the sea grass seasonality is still under consideration.

The Hellenic coasts are inhabited by Mediterranean species of different geographic affinities, e.g. Mediterranean endemic, eastern Atlantic warm-temperate, Amphi-atlantic tropical to (warm-) temperate and Indo-pacific tropical to (warm-) temperate, shaped by the Mediterranean geological and paleoclimatic history.

The Hellenic coasts belong to the eastern Mediterranean, where it seems to be floristically poorer than the western. Vicinity to the Atlantic, hard substrate coastlines, and separation into geographically isolated parts may have promoted colonisation and speciation in the western Mediterranean. Paleoclimatic and oceanographic differences between the Mediterranean basins during last sapropelic events also may have impacted the eastern basin's biodiversity.



Source: *Based on LAZARIDOU, 1994.*

Figure VI.14:
A. Mean qualitative dominance (%) of species number of main seaweed taxonomic groups on Hellenic coasts.
B. Quantitative dominance (%) of main seaweed taxonomic groups in the upper infralittoral of Milos Island and the south Aegean.

HABITAT TYPES

Benthic macrophytes, especially sea grass meadows, form important habitats providing nursery grounds for fish populations and also recycle nutrients and stabilising coastal sediments. Conserving habitats across their range is also likely to conserve species diversity within habitats, too. The 'Habitat Directive' (92/43/EEC) which aims to conserve flora, fauna and natural habitats across Europe mentions nine marine habitat types. Marine benthic vegetation was suggested as a tool to describe and map different habitat types, as well as to evaluate conservation status of the marine environment. The cartography of marine habitat types in Hellas was carried out within the framework of the implementation of the Directive (Figure VI.15), which aims for the sustainable management of a network of sites (areas), known as the Natura-2000 network. The marine habitat types, which are present in the Hellenic coastal ecosystem (Ministry of Environment, 2001), are described in the following paragraphs.

Habitat type 'Sandbanks which are slightly covered by sea water all the time' (code 1110)

This habitat type exists in open high hydrodynamic sandy and gentle sloping coasts, where the sand deposits can move on the sea floor like the sand dunes. This combination is common in many sites in the northern Aegean and Ionian Sea. The habitat type 1110 is often unvegetated. Nevertheless, under moderate hydrodynamic conditions two types of sea grass meadows are present:

- *Cymodocea nodosa* meadows grow in many sites (Figure VI.16). The upper limit of the meadow ranges from 0.2 m depth in sheltered to 3 m depth in semi-exposed coasts. The lower limit ranges from 5 to 10 (15) m depths. In general, their presence depends on the frequency of extreme weather conditions. A severe winter storm could eradicate the *C. nodosa* beds, but they can be re-established during the next spring since it is a fast growing species fruiting almost every year. Extensive patchy 'tiger type' meadows along with *Zostera noltii* occur in the north Aegean coasts. *Zostera*

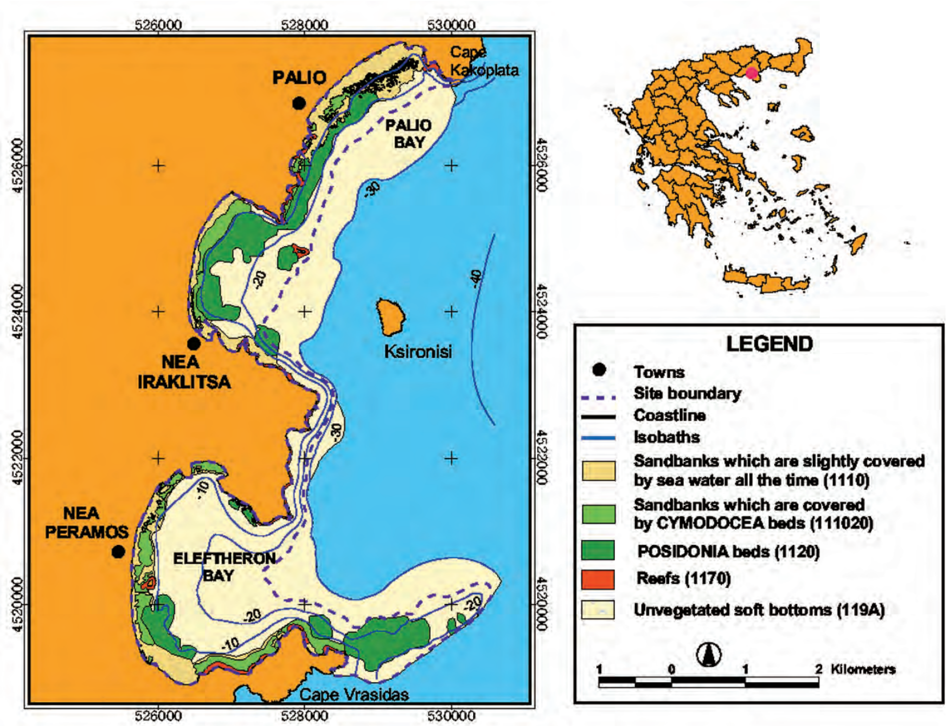


Figure VI.15: *Marine habitat types in the Elefteron Gulf, eastern Makedonia and north Hellenic coasts.*

Source: *NATURA, 2000.*

noltii exist also in the Strymonikos (Aegean Sea) and Amvrakikos (Ionian Sea) gulfs.

- *Halophila stipulacea*, a typical Lessepsian migrant of the eastern Mediterranean, form ephemeral meadows in free space of the unvegetated sand banks of the south, e.g. Rodos, Kriti and central Hellenic, e.g. Korinthiakos, Pagasitikos gulfs, coasts. Fast growth is its strategy to withstand severe winter storms and to sustain monospecific meadows.

Habitat type 'Posidonia oceanica meadows' (code 1120)

Posidonia oceanica, an endemic Mediterranean species, forms the most common and extensive sea grass meadows on the Hellenic coasts (Figure VI.12). On *Posidonia* leaves more than 150 photophilic algae have been recorded (brown algal genera of *Myrionema, Giraudia, Castagnea* and red encrusting algae of *Fosliella* and *Dermatolithon*, as well as small Ceramiales). On rhizomes more than 50 sciaphilic algae have been recorded (red algae of *Peyssonnelia* and the green algae *Halimeda tuna, Flabellia petiolata* and *Valonia utricilata*). The associated fauna comprises some hundreds of Hydrozoan, Bryozoan and Ascidian species (living on the leaves), as well as Polychaetes and Moluscs (living in the sediment, beneath the rhizomes). The Directive 92/43/EEC evaluates the meadows of *P. oceanica* as a priority habitat type.

The meadows of *Posidonia* extend to 20 (25) m depth in the north Aegean, but they are able to reach 30 m and 45 m depth in the central and southern Aegean, respectively. South of Kriti the maximum depth was recorded at 55 m. Since water transparency increases in the Aegean southwards (PAR attenuation coefficient (k) ranges from 0.12-0.3 at Makedonian coasts to 0.06-0.09 at Chios and Fournoi islands, central Aegean), the deeper growth limit of *Posidonia* seems to be related to light penetration. In the Ionian Sea the lower depth limit approaches 50 m depth. In sites of the north Aegean and the Ionian Sea where hydrodynamism is low to moderate, extensive meadows were found

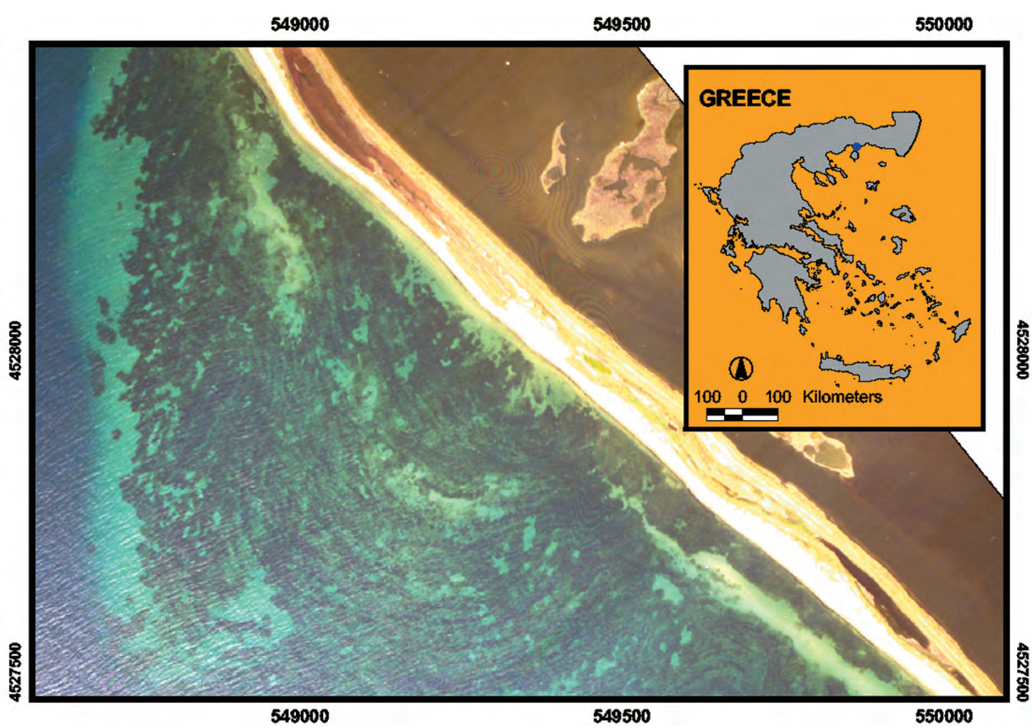


Photo: *S. ORFANIDIS.*

Figure VI.16: *An ortho photomap of Cymodocea nodosa and Zostera noltii meadow on the north Aegean coasts.*

in excellent representativity and conservation status (Figure VI.17). For example, in the eastern part of Limnos Island (north Aegean), an area known as 'Charos reefs', *Posidonia* form an extensive meadow covering about 115 km^2. Close to the beach dead leaves form thick one-meter high walls. Medium and small size meadows of good representativity and high conservation status also exist in many central and south Aegean areas.

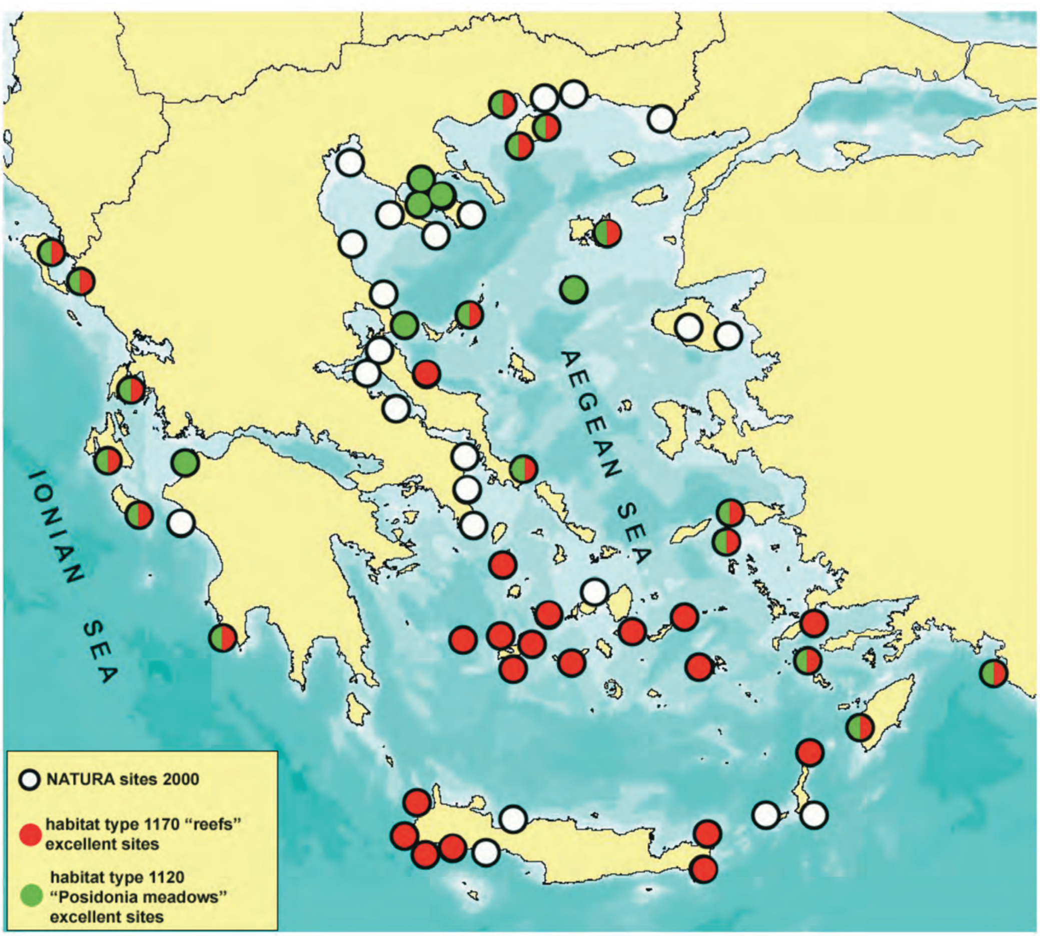
Habitat type 'Mudflats and sandflats not covered by sea water at low tide' (code1140)

This habitat type includes a shallow mudflat bottom not covered by sea water at low tide. Vegetation in this habitat type is not permanent due to periodic exposure of the bottom to climate factors prevailing during the low tide (Figure VI.18). Nevertheless, there are species that can grow during certain periods of time on mudflats like the seagrasses *Zostera noltii* and *Cymodocea nodosa*.

Habitat type 'Large shallow inlets and bays' (code 1160)

This habitat type occurs in semi-enclosed embayments where the depth usually does not exceed 10-15 m depth and the hydrodynamic energy is low. Meadows of the seagrass *Cymodocea nodosa* are the dominant vegetation element, together with the seagrass *Halophila stipulacea* and the green algae *Caulerpa prolifera*.

Populations of some *Cystoseira* species, such as *Cystoseira barbata* and *Cystoseira schiffneri*, are growing on small stones and dead shells. During the last decade of the 20th century the invasive form of *Caulerpa racemosa* is rapidly covering the



Source: *Based on Ministry of Environment, 2001.*

Figure VI.17: *Natura 2000 Hellenic sites, where the sites with habitat type 1120 and 1170 present excellent representation and conservation status.*

muddy sands of this habitat type (Figure VI.19).

Habitat type 'Reefs' (code 1170)

This habitat type includes the rocky substrata of the upper infralittoral zone, where the genus *Cystoseira* dominate (Figure VI.20). Hydrodynamic intensity affects the *Cystoseira* species composition, which often form dense populations in the upper infralittoral zone (0.2-1 m depth), but can survive at least to 35 m depth of the Hellenic coast.

- *Cystoseira barbata* is common in semi-enclosed bays and even in the small fishing ports. It is considered to be the most sensitive to the hydrodynamic conditions *Cystoseira* species and is, therefore, rare in the Aegean Sea, where the hydrodynamism is usually very high.
- *Cystoseira barbatula* grows in sites of moderate wave energy.

Photo: *P. PANAYOTIDIS.*

Figure VI.18:
Mudflat of Atalanti (north Evvoikos).

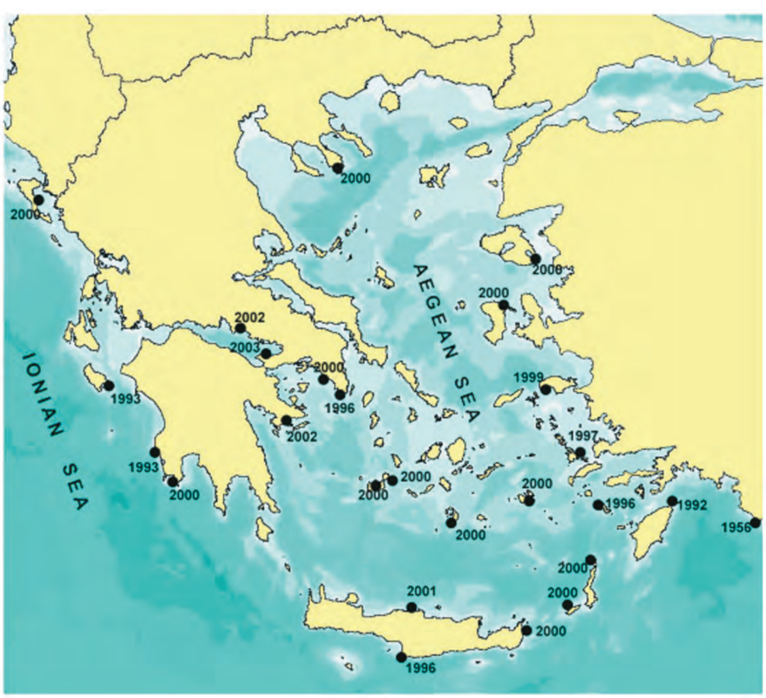


Figure VI.19:
Caulerpa racemosa's expansion on the Hellenic coasts.

- *Cystoseira brachycarpa* grows in sheltered areas.
- *Cystoseira compressa* often grows in moderate to high hydrodynamic conditions, being replaced by *C. corniculata* in high exposed sites and by *C. crinita* or *C. crinitophylla* in sheltered sites.
- *Cystoseira corniculata* grows in sites with high, but not direct, wave energy (oscillating zone).
- *Cystoseira crinita* grows in exposed as well as in sheltered sites.
- *Cystoseira crinitophylla* forms dense meadows in semi-exposed sites but also shows habitat similarities to *C. crinita*.
- *Cystoseira mediterranea* grows in exposed sites.
- *Cystoseira schiffneri* grows in the sheltered Aegean sites.

Other common components of the *Cystoseira* communities are the brown algae *Sphacelaria cirrosa, Halopteris scoparia, Padina pavonica and Dictyota* spp., the red algae *Jania rubens, Corallina granifera* and *Laurencia obtusa* and the green algae *Anadyomene stellata*, *Valonia utricularis* and *Dasycladus vermicularis*. In shallow and low hydrodynamic conditions sites fine sediments usually cover the free space between *Cystoseira* plants favouring the growth of *Cladophora prolifera*. Under high hydrodynamic conditions the species *Cystoseira corniculata* forms a pillow-like stratum on the rock favouring encrusting sciaphilic species and small epiphytes. Most common are the red algal genera *Titanoderma* and *Peyssonnelia*. Other common *Cystoseira* epiphytes comprise the red encrusting algae *Hydrolithon farinosum* and *Pneophyllum lejolisii*, as well as filamentous brown (mainly Ectocarpales), green (mainly Cladophorles) and red algae (mainly Ceramiales).

The habitat type 1170 is very common on the Hellenic coast. Sites where the habitat type 1170 occurs in excellent representativity and high conservation status can be found in all the capes of the mainland and the islands (Figure VI.17).

Habitat type 'Marine caves submerged or semi-submerged' (code 8330)

Marine caves occur mainly along rocky calcareous coasts. Due to scarce light conditions the dominant vegetation is sciaphilic (Figure VI.21), with the most common species being *Flabellia petiolata, Peyssonnelia squamaria* and *Peyssonnelia rubra*. Typical examples of high representativity and high conservation status occur

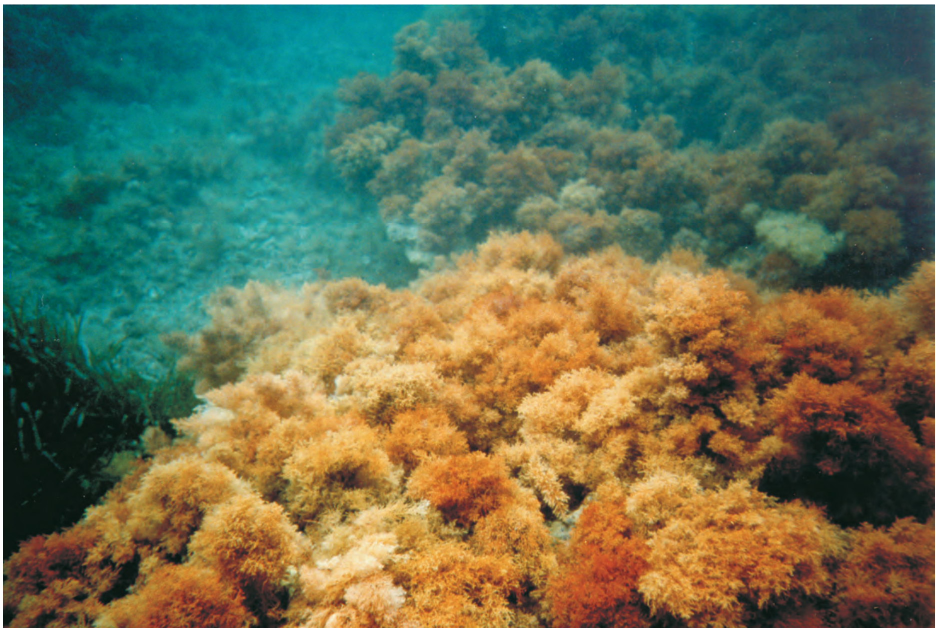


Photo: *P. PANAYOTIDIS.*

Figure VI.20:
Cystoseira 'forest' in Kefallonia Island, Ionian Sea.

in the marine park of the Sporades and the inner Ionian archipelago.

CONCLUSIONS

The evolution of the Hellenic flora, as a part of the Mediterranean flora, provides an example of short-term diversification following the geological and paleoclimatological conditions that prevailed during the last 5 million years. Several communities dominated rocky and soft substrates form diverse and extensive marine coastal habitats, most important of *Cystoseira* and *Posidonia* species. Latter long-lived species, unfortunately, suffer more from the human activities that change composition and diversity of marine flora.

Further investment on taxonomical, ecophysiological and manipulative field studies will increase our knowledge of marine macrophytes, which, beside others, indicates human induced changes in the marine environment.

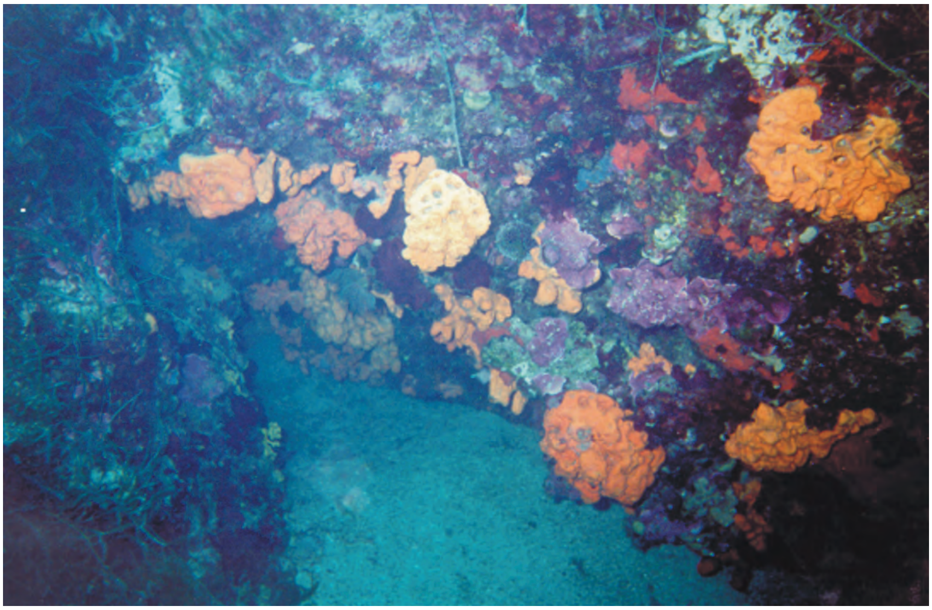


Photo: *M. SALOMIDI.*

Figure VI.21: *Sciaphilic vegetation in a marine cave of Cape Sounion, Attiki.*

VI.4. ZOOBENTHOS - SOFT BOTTOM FAUNA

SOME NECESSARY DEFINITIONS

Zoobenthos includes all those animals living in or on the sea floor. The term **community** has been largely used to describe any group of organisms belonging to a number of species that co-exist in the same habitat or area and interact through trophic and spatial relationships. Main zoobenthic animal groups in soft bottom communities are the annelids (class: Polychaeta), molluscs, echinoderms (urchins, sea stars) and crustaceans (crabs, shrimps, isopods) (Figure VI.22). Minor benthic groups often termed as miscellanea include sponges (class: Porifera), Ascidia, Bryozoa, Sipuncula etc.

The community interacting with the non-living (abiotic) environment forms the **ecological system** or **ecosystem.** Two other terms frequently used by ecologists are **habitat** and **niche.** The former means the place where a species can be found and the latter the ecological function of the species in its community or habitat.

Habitat is the organism's address and the niche is its profession (ODUM, 1997)

The main soft bottom habitat types of the Hellenic benthic ecosystems (coastal and marine) are given in Table VI.7. These are derived from an adjustment of the classical bionomical system of community types **(biocoenoses)** described by PERES & PICARD (1964) which applies for the whole Mediterranean and Europe. For example, the biocoenosis of the Coastal Terrigenous Muds (VTC) has been originally described from the circalittoral zone [bathymetric zone with upper limit the lowest extent of the marine angiosperms (around 35 m) and with lowest

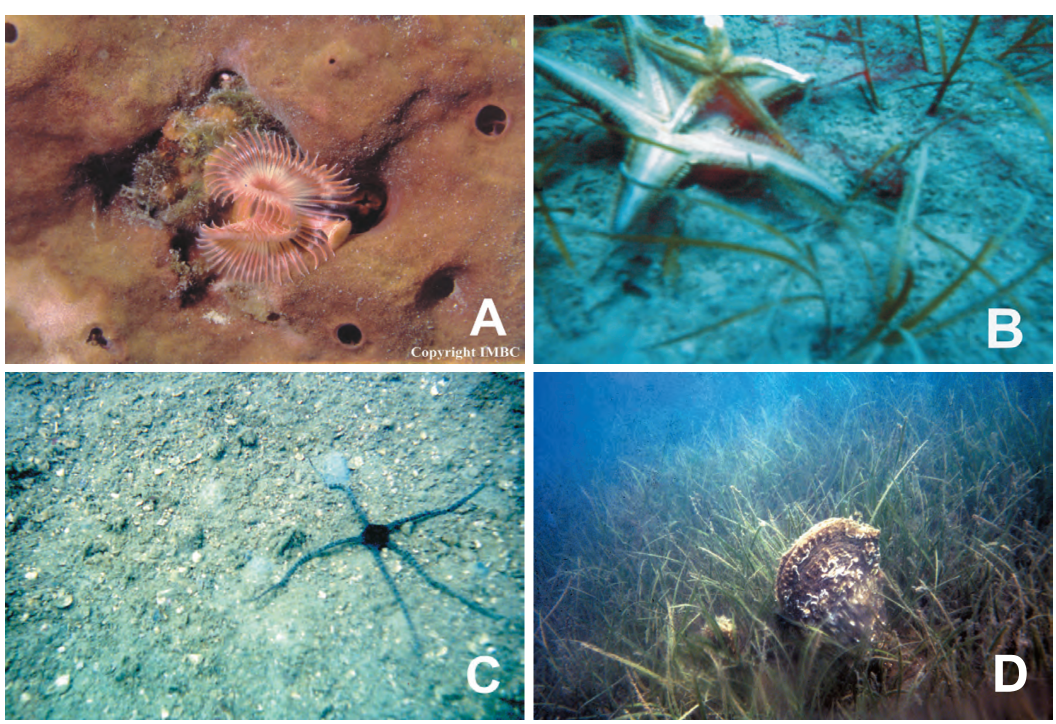


Figure VI.22: *a: Serpula vermicularis (class Polychaeta); b: sea stars c: ophiuroid (class Echinodermata; d: Pinna nobilis (class Mollusca).*

Photo: *V.A. CATSIKI (b, c, d).*

(deepest) limit the lowest extent of schiaphilic algae (70-120 m)]. However, in Hellenic ecosystems it is also encountered in semi-enclosed gulfs of shallower depths 20-30 m. The circallitoral hard substrate of coralligenous community is also included in the table as it is usually encountered in samples collected using a soft bottom sampling device. Marine algae as well as zoobenthos communities in hard bottoms are addressed in detail in Chapters VI.3 and VI.5 and zoobenthos communities occurring in the transitional waters (e.g. deltas and lagoons) are described in Chapter VI.1.

The most important macrozoobenthic species characterising the main benthic communities in the Hellenic marine and brackish environment are given in SIMBOURA & ZENETOS (2002).

In this context, it is noteworthy to mention the term **water body type (WBT)**, addressed in the context of WFD (European Framework Directive). It refers to large entities of water bearing the same characteristics concerning main factors such as exposure, depth and substrate type within coastal waters delimited by one nautical mile from the baseline. Generally, the scheme adopted for the classification of habitats into WBT is based on factors such as depth, type of substrate, and phytal cover. In the Mediterranean ecoregion, five main coastal WBT have been defined: rocky deep exposed, rocky deep shallow, sedimentary deep exposed, sedimentary shallow sheltered and very sheltered bays.

How we collect macrozoobenthos samples

The gear most widely employed for sampling zoobenthos includes Ponar grab (0.05 m^2 sampling surface) for shallow enclosed areas (5-20 m depth) and Box corer (Figure VI.23), Van Veen and Smith-MacIntyre grabs with sampling surface 0.1 m^2 operated from larger vessels at greater depths. In the midlittoral sands samples are collected by

Table VI.7: *Main Benthic habitat and community types (biocoenoses) in Hellenic waters. Zoobenthos of the not shadowed types is described in separate chapters of this volume.*

Abbreviations used: VTC=Coastal Terrigenous Muds. LEE=Eurythermal, Euryhaline Biocoenosis (Met In lagoons and estuaries); SFBC= Fine Well-Sorted Sands; SFHN=Upper Fine Sands; SGCF=Coarse Sands and Fine Gravels under the influence of Bottom Currents; SVMC=Calm Water Muddy Sands; AP=Photophilous Algae; DC=Coastal Detritus Bottoms; C=Coralligenous; DE=Muddy Detritus Bottoms; DL=Open Sea Detritus Bottoms; VP=Deep Sea Muds.

Type of habitat	PERES & PICARD, 1964	Description
Midlittoral sands	Midlittoral sands	
Deltas	LEE	Brackish, deltaic ecosystems
Lagoons	LEE	Transitional lagoons
Sands and muddy sands	DE	Mixed sediment (shallow 30 m or deeper 30-100 m) muddy detritus bottoms
Muddy sands with phytal cover		In or close to phytal meadows of macroalgae or angiosperms *(Zostera, Posidonia, Caulerpa)*
Shallow muddy sands	SVMC	Muddy sands in protected areas
Shallow muds	VTC	Shallow (sublittoral) muds Sub-community of muddy bottoms with *Amphiura filiformis*
Shallow sands	SFBC, SFHN	Shallow sands (well sorted or very shallow sands)
Deeper coarse sands	SGCF	Coarse sands in high energy environments
Deeper Sands with detritus	DC DL	Deeper sands with biogenic fragments or Coastal detritic bottoms deep circalittoral bottoms or open sea detritus bottom
Coralligenous	C	Circalittoral hard substrate sciaphilic algal community
Circallitoral muds	VTC	Muds deeper than 50 m (typical VTC)
Bathyal muds	VP	Communities of bathyal muds

means of corers (Figure VI.24).

The sediment collected is sieved on board through 1 mm mesh sieve (usually in surveys and monitoring studies), 0.5 mm mesh (in research projects, deep sea ecosystems) or via a series of sieves (2 mm, 1 mm, 0.5 mm, 0.025 mm) in specific cases (Figure VI.25).

Photo: A. DOGAN.

Figure VI.23: *Box corer sampler.*

Photo: N. PAPAGEORGIOU.

Figure VI.24:
Corer used in midlittoral sands.

Photo: A. DOGAN.

Figure VI.25:
The sediment collected in the corer is sieved via a series of sieves.

BENTHIC DIVERSITY

Species number estimates in a given area are dependent on many factors including habitat (community type), depth, anthropogenic impact, sampling technique, sampling effort and degree of expertise.

Sampling technique (mesh size): The majority of benthic species are >1 mm in size. Experimental studies (Table VI.8) have shown that about 80% of the benthic fauna are collected with a mesh size of 1mm, while about 20% are small-sized species. Yet, given the time and effort needed to identify the small specimens, most studies compromise with the use of 1mm sieve.

Sampling effort

The total species recorded in an area increases with the sampling effort, that is the total number of samples collected (Figure VI.26).

Sampling depth and geographic area

The overall species number as well as mean population density (abundance) decreases with depth (Figure VI.27). This trend is considered to be regulated by food resources' availability and quality of food. In the continental shelf, macrofaunal species richness[1] is significant. TSELEPIDES & ELEFTHERIOU (1992) showed that pronounced decrease with depth in diversity and abundance of the benthic macrofauna extends beyond the continental shelf into the continental slope and abyssal plain. The decline of species with depth is more pronounced between 40 and 100 m depth, showing a second dramatic drop beyond 500 m depth.

The pattern of both species' number and abundance is the same in the north and south Aegean (Cretan Sea). Yet Figure VI.27 shows the pronounced difference in these parameters between the two seas. As exhibited with other biological parameters, benthic diversity in the north Aegean is always richer in comparison to that in the south Aegean.

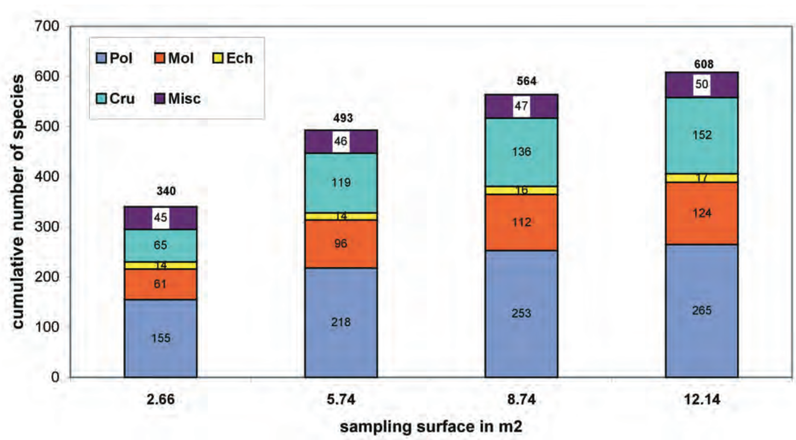
Overall assessment of species diversity

One of the fundamental meanings of biodiversity lies in the species' diversity. Despite the well-established oligotrophy of the eastern

Table VI.8: *Species number (S) retained in two sieves >1mm vs <1mm in northeastern Aegean.*

Year	S total	S > 1 mm	S > 0.5 mm not retained at 1 mm mesh sieve
1998	493	408	85
1999	317	191	126
2000	307	205	102
Total	**608**	**478 (78.6 %)**	**130 (21.4 %)**

Data source: *KEYCOP project (HCMR benthos group).*



Source: *KEYCOP project (HCMR benthos group).*

Figure VI.26: *Example of cumulative increase with sampled surface, northeastern Aegean, depths 63-1300 m. (Pol=Polychaeta, Mol=Mollusca, Cru=Crustacea, Ech=Echinodermata, Misc=various minor taxa).*

[1] Species richness is also referred as species variety, species diversity and in this text mostly as species number.

Mediterranean, a term mostly used to denote waters with low primary productivity; the Hellenic Seas are by no means a poor area (in terms of species diversity). The Hellenic scientific community, which has developed rapidly since the beginning of 1980, has taxonomists who are proficient with experience in many benthic taxa. As a result of intensive (seasonal small-scale studies) and extensive (single qualitative studies) surveys - see map of areas covered in Figure VI.28 - the Hellenic Seas host > **3 200** benthic species (Table VI.9). However, it is believed that the actual species number should be higher, if taxonomic efforts are made to cover several groups (i.e. Nemertea, Oligochaeta, Foraminifera) for which there is currently lack of expertise.

The Hellenic marine ecosystems support a surprisingly high variety of marine life. The species numbers according to geographic area studied are presented in Figure VI.29. The numbers are only

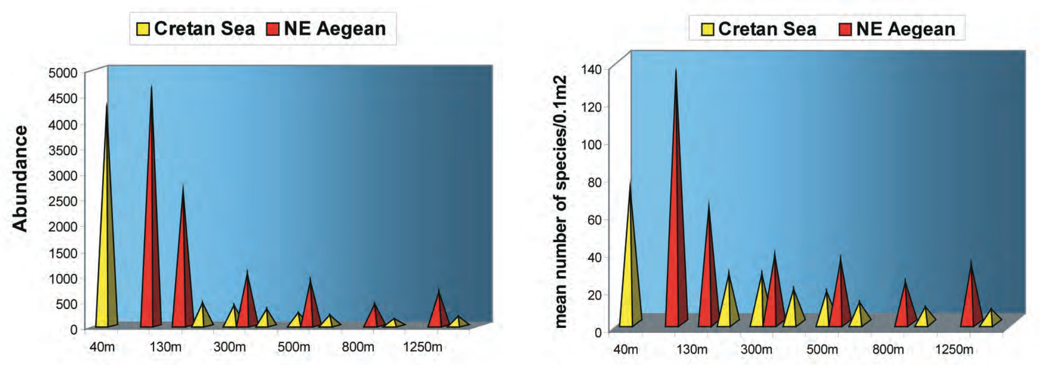


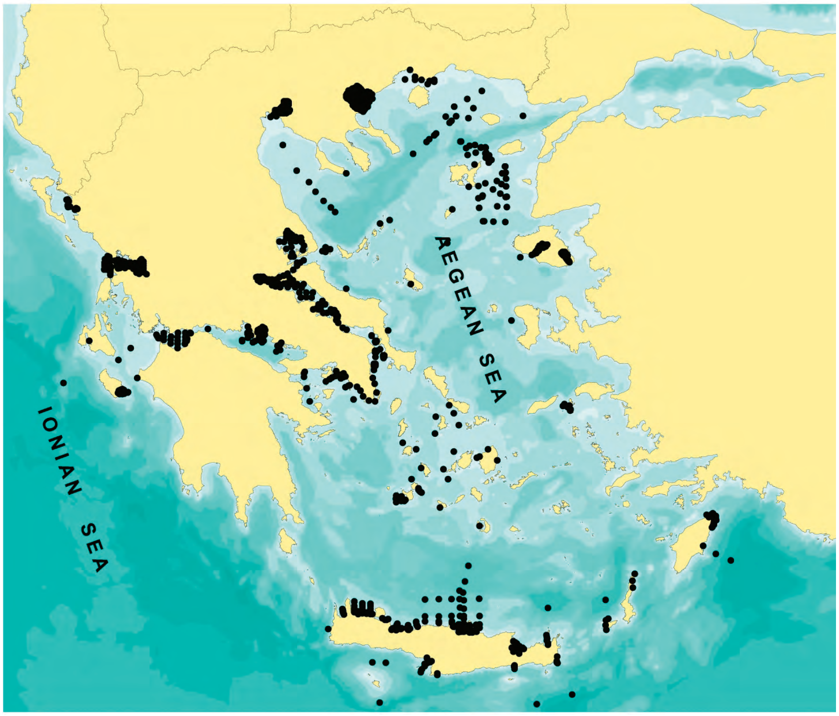
Figure VI.27: *Trend in benthic species number (S) and Abundance (no of individuals per m2) with depth.*

Source: *Based on TSELEPIDES, 1992; KEYCOP Project.*

Table VI.9: *Species diversity per benthic group.*

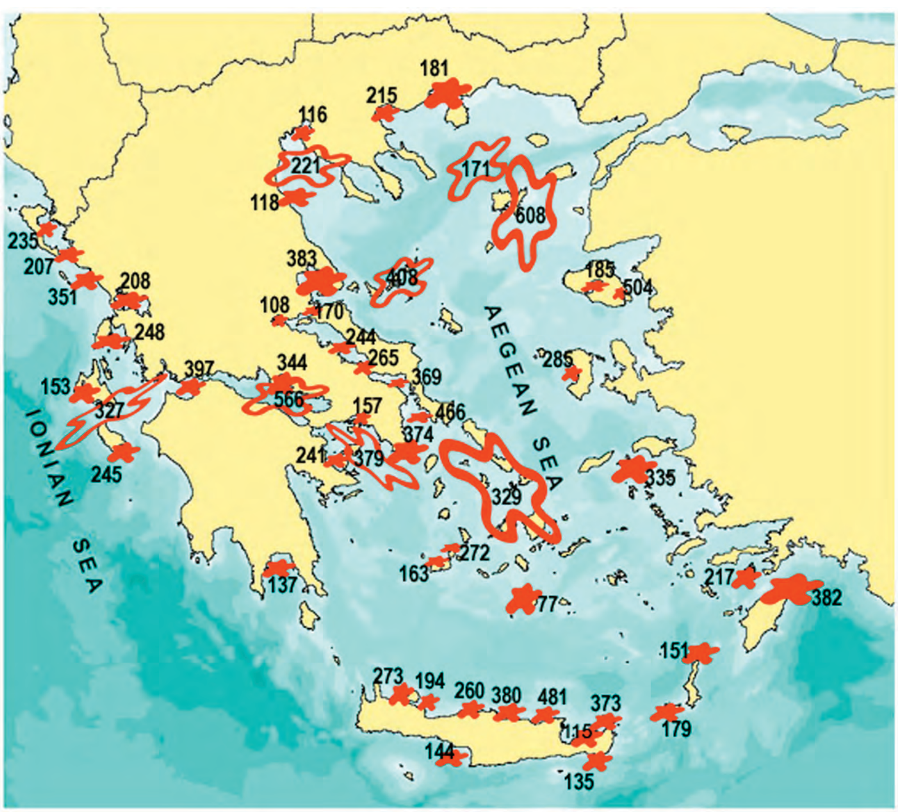
Benthic phyla/groups	Number of species	Source
Polychaeta	753	SIMBOURA & NICOLAIDOU, 2001
Mollusca	**1092**	KOUTSOUBAS, *et al.*, 1997
Bivalvia	308	DELAMOTTE & VARDALA-THEODOROU, 2001
Prosobranchia	515	ZENETOS *et al.*, 2005
Opisthobranchia	159	
Heterobranchia	82	
Scaphopoda	12	
Polyplacophora	16	
Echinodermata	107	PANCUCCI – PAPADOPOULOU, 1996
Crustacea	674	KOUKOURAS *et al.,* 2001
Amphipoda	260	
Isopoda	74	
Tanaidacea	18	
Cumacea	52	
Decapoda	252 (-14 pelagic)	
Cirripedia	18	
Porifera	200	VOULTSIADOU, 2005
Bryozoa	200	GANIAS, pers. commun.
Anthozoa	88	CHINTIROGLOU *et al.,* chap. VI.5
Ascidia	67	CHINTIROGLOU *et al.,* chap. VI.5
Sipuncula	17	MURINA *et al.*, 1999
Others (Foraminifera, Nemertea, Hydrozoa,etc.)	20	Grey literature

Note: The table includes zoobenthic taxa of hard substrata plus some benthopelagic species among Crustacea and Mollusca.
Source: *monographs, database, experts, latest publications.*



Source: *HCMR, UoA, various sources.*

Figure VI.28:
Location of macrozoobenthos sampling stations. Colours indicate stations studied in the framework of different projects.



Source: *HCMR, UoA various sources.*

Figure VI.29:
Total species of macrozoobenthos encountered at major geographic areas. Detailed area coverage as shown in Figure VI.28.

indicative since they are derived from different groups (taxonomic expertise), using different gear (mesh size sieves), and varying sampling effort (from 1 to 12m^2 of sampling area). A series of biogeographic studies has been published recently, showing that the Aegean is the second richest area in species numbers, among the Mediterranean and Black Sea regional seas. They have also demonstrated that the biodiversity indices, as calculated from polychaetes, are higher than expected and that this extreme biodiversity richness is attributable, to certain degree, to the number and total surface of the Aegean islands. The latter is in accordance with the island biogeography theory (ARVANITIDIS *et al.*, 2002 for a review).

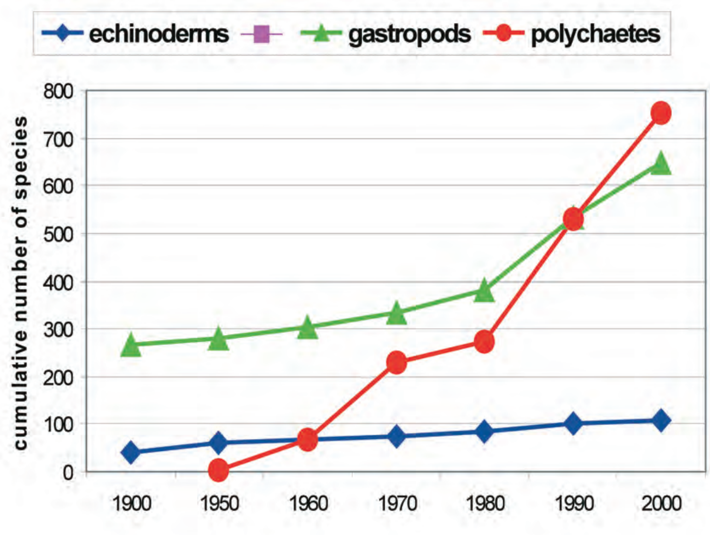
Trend in species number with time

The number of species recorded in the Hellenic Seas constantly increases with new studies either in unexplored bathymetric zones or unexplored geographic areas. Figure VI.30 demonstrates the trends in total species number for some of the most common zoobenthic groups (polychaetes, echinoderms, gastropods). Two main conclusions can be drawn from the curves formed by the numbers of gastropod and polychaete species: a) the rate of species reporting has been almost exponential from 1980 onwards; indeed, the efforts of the last two decades, have rendered many new records for Hellas including exotic species (Chapter VIII.7) and b) there is no plateau in those curves, a fact which is indicative of the relatively limited scientific efforts made so far and denotes that a significant number of species from the Hellenic Seas await to be reported or described in the years to come.

Species Abundance

Abundance, which is the number of individuals per m^2, is not informative enough as a stable indicator for the state of the ecosystem because it is too variable to show meaningful changes. In addition to depth and sediment type, abundance estimates depend on settlement processes and size of individuals.

Abundance values for ‘normal’ ecosystems in Hellenic waters may vary from: 217 ind/m^2 (average for the Kyklades plateau; ZENETOS *et al.*, 1991) to 619 ind/m^2 and 1439 ind/m^2 (average for the National Marine Park of Alonnisos – northern Sporades; SIMBOURA *et al.*, 1995). In disturbed ecosystems, abundance can reach values as high as 8695 ind/m^2 or 4428 ind/m^2 (Thermaikos Gulf). Such extremely high values are characteristic of very disturbed ecosystems, either from fisheries activities (the former) or from domestic and industrial pollution (the latter). In both cases, a few opportunistic species dominate at the expense of others. The contribution of the main animal groups is also different in disturbed ecosystems (Chapter VIII).



Source: *SIMBOURA & ZENETOS (in press); HCMR data base.*

Figure VI.30:
Time evolution of number of species for some common groups.

Extreme environments in the Aegean Sea: the case of benthic fauna associated with sublittoral hydrothermal vents

Sublittoral hydrothermal activity in the Aegean Sea has been detected along the Hellenic Volcanic Arc near the islands of Nisyros, Santorini and Milos as well as in Methana (Figure VI.31 and VI.32). However, the macrofaunal communities of shallow hydrothermal vents have been extensively studied only in Paleohori Bay, Milos Island (THIERMANN *et al.*, 1997) .

The influence on hydrothermal activity was

Photo: *IMBC.*

Figure VI.31:
Hydrothermal vent in Paleohori Bay, Milos Island.

Photo: *A. MALLIOS.*

Figure VI.32:
Milos Island 105m deep (taken with ROV 'Achilleas'). White spots indicate bacteria

evidenced by a general decrease in fauna both in abundance and species number along transects from the sea grass beds to the algobacterial mats, whereas in the 'normal biotope' no trend in faunal distribution from the sea grass bed to a sandy substrate was observed. The *'Hydrothermal Area'* is characterised by high temperatures, high sulphide concentrations, high salinity and low pH values even at the uppermost sediment layer (Figure VI.31 and VI.32). Here, the sediment was black, covered by a whitish layer of bacteria, algae and cyanobacteria and inorganic precipitates. The gastropod *Cyclope neritea* was the only species recorded in considerable abundance, with relatively large and highly mobile individuals (on average 144 ind/100 cm^2).

Deep Seas

It has been perceived that biological diversity in the deep sea is as high as on land, but fewer species have been described to date. In the deep sea, the distribution and abundance of benthic communities is closely related to the quality of food input to the seafloor. In the Hellenic Seas, compared to other areas of similar latitude and depth, there is a general impoverishment of deep-sea benthos, from microbes and meiofauna (see text on meiofauna this chapter) to macrofauna (TSELEPIDES *et al*., 2004). The observed species composition conforms basically to the bathyal mud (VP) biocoenosis mentioned by PERES & PICARD (1964).

Up-to-date the benthic ecosystems in the deeps are investigated by employing a) standard benthic sampling gear b) benthic landers c) remote operated Vehicles operating down to depths of 2 000m, and d) the submarine 'Thetys'. During a latest expedition of the RV 'Aegaeo' (April 2005) accompanied by the HCMR submarine 'Thetys' and the ROV 'Achilleas' (Figures VI.33, 34), a relatively high species richness was witnessed in the deep waters of the Central Aegean Sea (Figure VI. 35).

Little is known on the ecology of deep sea benthic fauna in the eastern Mediterranean. In 1987, in an effort to get information from the greatest depths of the eastern Mediterranean, the

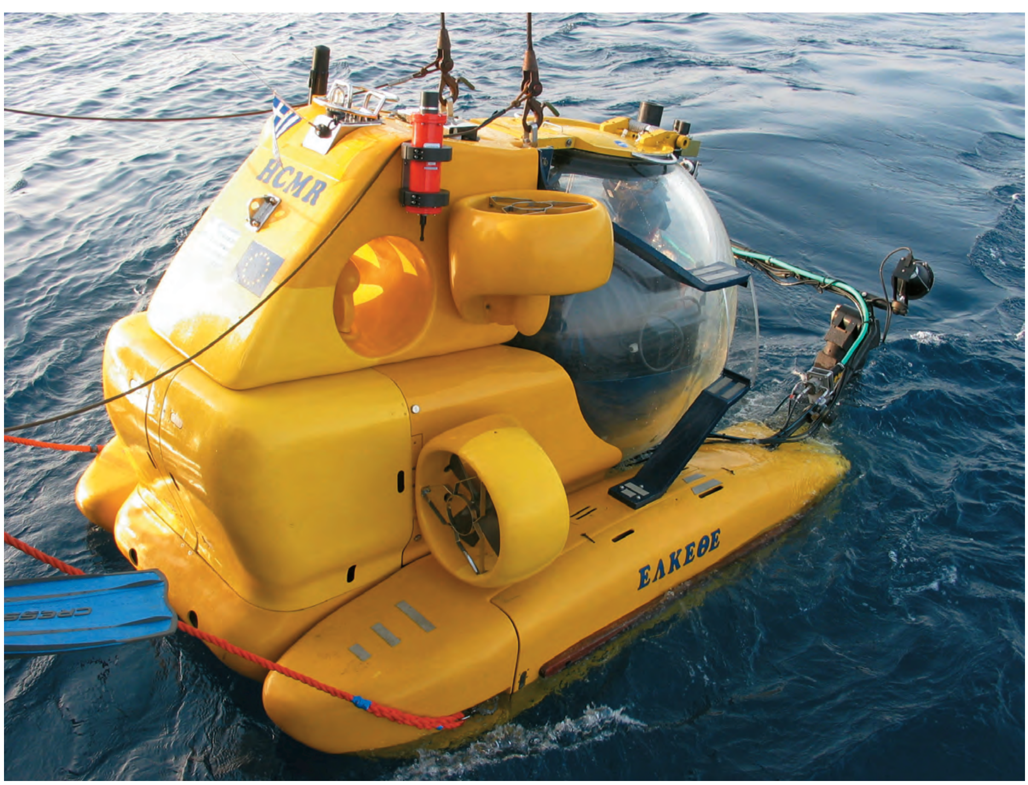


Figure VI. 33: *Submersible 'Thetys': max operating depth 610 m.*

Photo: *C. SMITH.*

pronounced impoverishment of the macrobenthos below 1 000 m was confirmed. However, later studies revealed that benthic life exists even beyond 1 500 m (average species number 7.7 species/0.1m^2, abundance 710 ind/m^2 at 1 560 m) (TSELEPIDES *et al.*, 1997).

During the RV 'Meteor' expedition, in January 1998, the structural and functional diversity of the benthic system of the highly oligotrophic eastern Mediterranean deep sea was investigated. A total

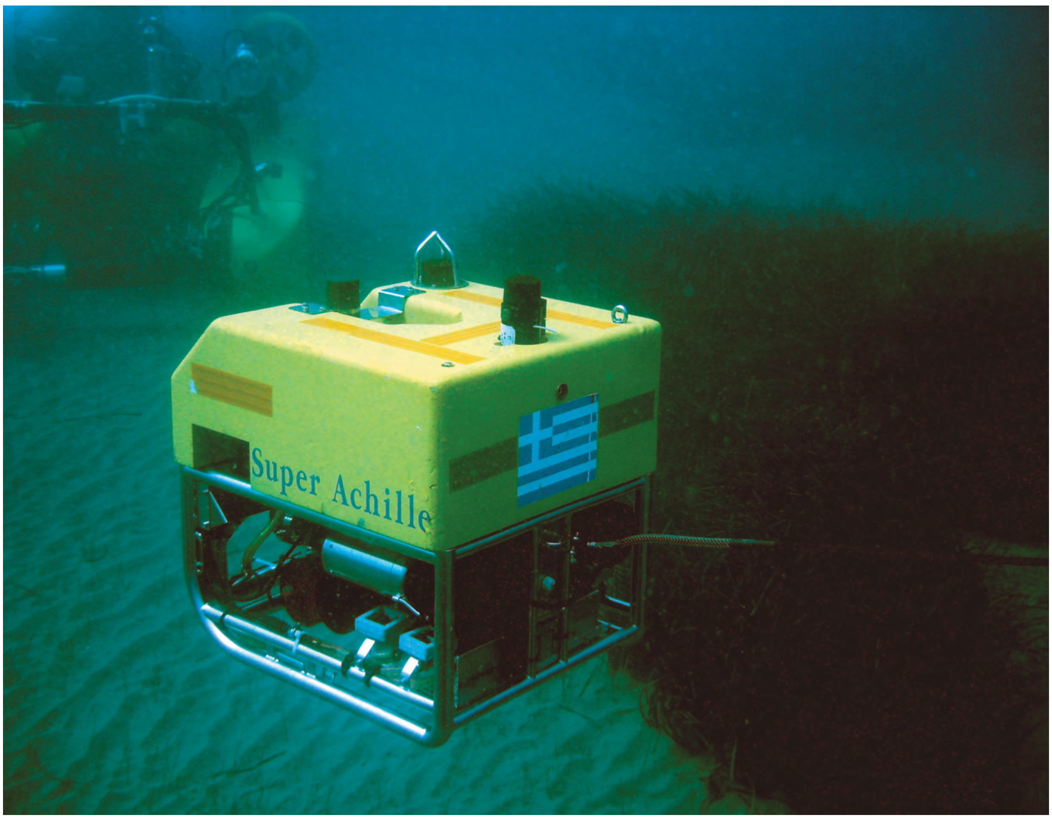


Photo: *M. SALOMIDI.*

Figure VI. 34:
ROV 'Achilleas' max operating depth 1 000 m.

Photo: *A. MALLIOS taken with ROV 'Achilleas'.*

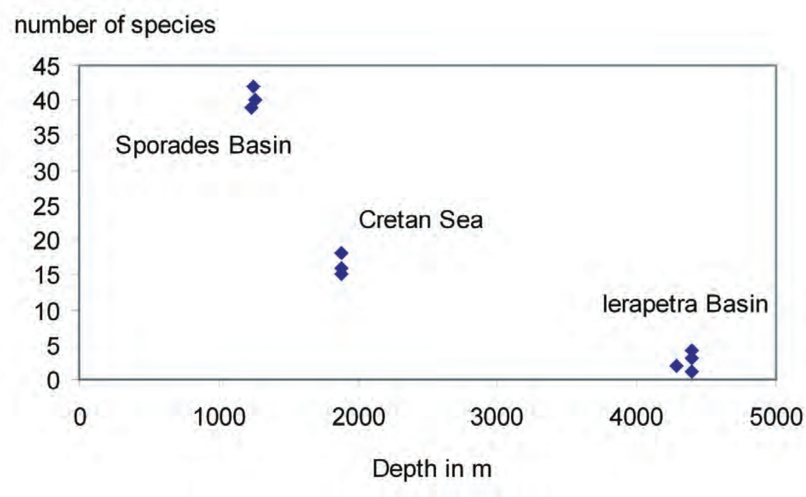
Figure VI. 35.
A ray fish (Raja sp) feeding on benthic fauna in the deep muds, Kythnos, Aegean Sea.

of 59 taxa were collected from 10 stations in the Sporades Basin, Cretan Sea and Ierapetra Basin, at depths between 1 267 and 4 394 m (Figure VI. 36). The average species richness was highest in the Sporades Basin, with 39–42 taxa/0.25 m^2 and lowest at stations below 4 000 (min the Ierapetra Basin, with 1–4 taxa /0.25 m^2). In the Cretan Sea at 1 840 m depth, 11–16 taxa /0.25 m^2 were found. (KRONCKE *et al.*, 2003). Abundance was also highest (81–86 ind/0.25 m^2) at the shallowest stations at about 1 200 m depths, i.e. in the Sporades Basin, and lowest at the stations below 4 000 m, i.e. Ierapetra Basin (1–4 ind/0.25 m^2).

Average density and number of taxa were significantly negatively correlated with depth and/or distance to the nearest coast, and positively to the TOC concentration of the sediments. Numbers of taxa and abundance decreased generally with depth, although lowest numbers were not found at the deepest stations but in the extremely oligotrophic Ierapetra Basin (KRONCKE *et al.*, 2003).

The macrofauna communities were dominated by polychaetes even at the deepest stations exceeding 4 000 m where abundance was low (KRONCKE *et al.*, 2003). Bivalvia and Scaphopoda were found only north of the Sporades in 1 242 - 1 267 m depth, where also Isopoda and Cumacea were found in higher percentages.

A decrease in megafaunal species diversity, abundance and biomass has been also documented for depths down to 1000 m in the Cretan Sea (KALLIANIOTIS *et al.*, 2000) and to 2 800 in the south Greek Ionian (COMPANY *et al.*,. 2004). In the latter site and below 1 000 m, there is a slight decrease in decapod crustacean biomass and abundance in comparison to sites in the western Mediterranean. In shallower depths (600-999 m), the same animal group shows greater abundance and biomass, mainly due to the presence of unexploited stocks of the aristeid shrimp *Aristaeomorpha foliacea.* This commercially important species, together with the more rare shrimp *Aristeus antennatus*, represent a new fishing resource for the Greek Ionian, the exploitation of which requires special attention due to habitat and species vulnerability (PAPACONSTANTINOU & KAPIRIS 2001).



Source: *Based on KRONCKE et al., 2003.*

Figure VI. 36:
Average species number/0.25 m ^{2} during the 'Meteor' cruise in January 1998

VI.5. ZOOBENTHOS - HARD SUBSTRATA COMMUNITIES

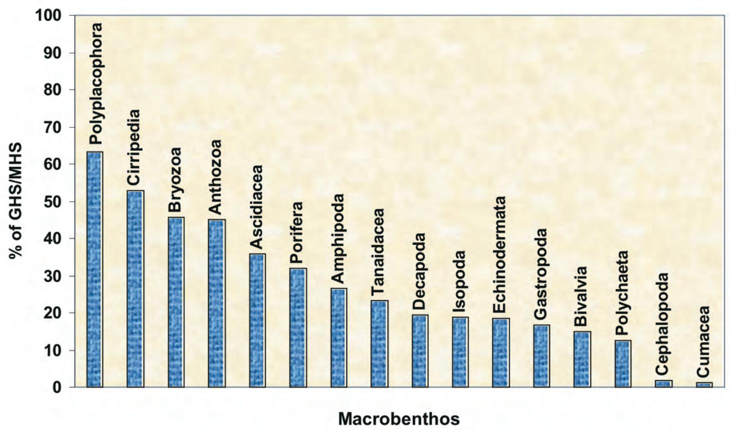
The study of the hard substrate benthic communities, whose complexity can sometimes be compared with that of the coral reefs, has been an attractive subject for marine biologists. Studies of hard substrate communities outnumber those on soft substrata, mostly due to the difficulties involved in the approach to rocky bottoms (sampling with SCUBA-diving). The main environmental factors that determine the community structure and are supported by several authors, are humidity, light, hydrodynamics, salinity and sedimentation.

A review of the studies on Mediterranean benthic ecosystems revealed that the vast majority of these research attempts took place in the western basin and the Adriatic Sea (ANTONIADOU, 2003). The first information on the bionomy of coastal hard substrate communities in Hellenic waters was derived from the cruises of the Calypso in the southern Aegean (PÉRÈS & PICARD 1958) though their quantitative study started only recently (CHINTIROGLOU & KOUKOURAS 1992). This revision attempts to gather the available information from the Hellenic Seas. Such a project, however, could only be on a small scale, due to paucity of relevant data from quantitative studies.

BIODIVERSITY: QUALITATIVE ASPECTS

The bulk of information on hard substrate macrobenthic species in the Hellenic waters is derived from publications that deal with the most important macrobenthic groups, such as Porifera, Anthozoa, Polychaeta, Sipuncula, Mollusca, Crustacea, Echinodermata, Bryozoa and Ascidiacea. However, none of these works deals exclusively with hard substrate communities.

In addition to sporadic information on the benthic fauna of hard substrate in Hellenic Seas, which is found in a number of faunistic and ecological papers (see CHINTIROGLOU *et al.*, 2004), a comprehensive study of the hard substrata communities of the lower infralittoral zone in the north Aegean has been recently presented by ANTONIADOU (2003). From the recorded 3 200 macrobenthic species recorded in Hellenic waters (Chapter VI.3), 1 163 species inhabit hard substrate. Compared with the overall Mediterranean area's estimates, the Hellenic seas apparently harbour 3.3 % to 75 % of the Mediterranean marine species, with large differences depending on the group considered. For the species that live on the hard substrate the percentage ranges between 1.1 % and 63.3 % (Figure VI.37).



Source: *Compiled by authors based on various sources.*

Figure VI.37:
Percentage of the number of species, per taxon, recorded from hard substrate biotopes (GHS) to the Mediterranean area's estimations (MHS).

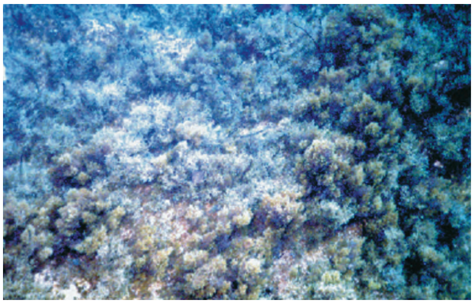
QUANTITATIVE ASPECTS

In the middle of the previous century, PÉRÈS & PICARD (1958) postulated that the northeastern Mediterranean consists of a homogenous region. Rather recently, BIANCHI & MORRI (1983) described the physiognomy of benthic communities in a south Aegean island (Kos) and argued that a distinction should be made between the north and the south sub-areas. This seems to be true at least in the Aegean Sea, where benthic communities are rather differently distributed. Most of the quantitative information on benthic communities is derived from the sublittoral zone, where two major types were described in Hellenic waters: (1) the photophilic algae community (PAC) (Figure VI.38), and (2) the sciaphilic algae community (Figure VI.39). The former seems to expand mainly in the north,

Figure VI.38: *Representative organisms of the photophilic algae communities.*

The nudibranch *Flabellina* sp., a mollusc frequently found inhabiting various hydrozoans on rocky bottoms.

Photo: *C. ANTONIADOU.*



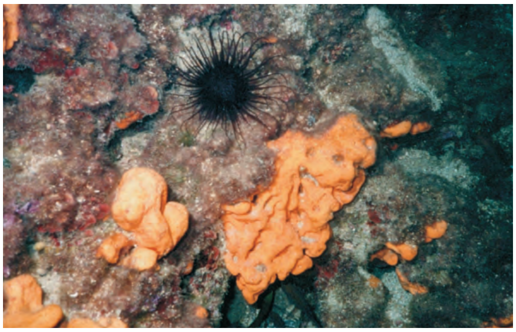
General aspect of the photophilic algae community, where the brown alga *Cystoseira* sp. abounds.

Photo: *C. ANTONIADOU.*

Figure VI.39: *Representative organisms of the sciaphilic algae communities.*

Eunicella cavolinii, a sea fan that inhabits the sciaphilic algae community.

Peltaster placenta, a starfish frequently found inhabiting the sciaphilic algae community.



General aspect of the sciaphilic algae community, where the sponge *Agelas oroides* abounds.

Photos: *C. ANTONIADOU.*

whereas the latter develops in deeper sites in the south.

The hard substrata communities can be separated on the basis of vertical zoning (supralittoral, midlittoral, upper- and lower sublittoral zones) and of the water quality (ports, *Ulva* facies). Moreover, the substrate's architecture influences the separation of groups, either as an abiotic feature (artificial: concrete, natural: granite, limestone) or as a biotic factor of microhabitat formation (e.g. the assemblages of symbiotic fauna in sponges and *Cladocora*).

There are more than 1 000 species recorded from quantitative or semi-quantitative researches of hard substrate communities on the coasts of the Aegean. The grouping of these species in higher taxa showed that, apart from the numerous taxa, there are three dominant groups, which are Polychaeta, Mollusca and Crustacea with percentages of 28.1%, 27.5% and 24.5%, respectively (Figure VI.40). The diversity indices (H') also show significant similarities, especially when they refer to specific communities, e.g, *Mytilus galloprovincialis*, *Anemonia viridis, Aplysina aerophoba,* etc. In contrast, the values are higher in the communities of photophilic and sciaphilic algae (Table VI.10). Frequently found species per

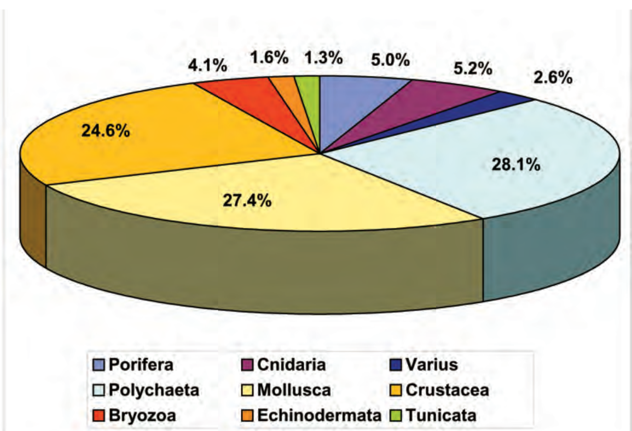


Figure VI.40: *Percentages of species on various taxa, recorded from hard substrate communities in the Hellenic seas and the Turkish coasts of the Aegean.*

Table VI.10: *Species richness of the dominant taxa (Pol = Polychaeta, Mol = Mollusca, Cru = Crustacea) total number of species (S) and Shannon-Wiener (H') diversity index of hard substrate community types.*

COMMUNITY TYPE	S	Pol	Mol	Cru	H'
Supralittoral	5		3	2	
Midlittoral	12		9	3	
Ports	93	25	6	16	3.15
Sciaphilic algae	314	77	111	59	5.18
Photophilic algae	141	50	29	44	4.35
FACIES of PAC					
Clear-water Algae	165	61	40	60	5.24
Mussels, Sea anemone, Slightly polluted-water Algae	107	41	27	28	3.80
Polluted-water Algae	126	31	26	46	
Sponge assemblages	110	38	17	39	3.33
Coral *Cladocora*	207	87	53	50	

Source: *ANTONIADOU & CHINTIROGLOU, 2005.*

community type (e.g. main group) are shown in Table VI.11.

EXPLOITED ORGANISMS

The review of the relative literature has revealed that 135 species are under exploitation in the Hellenic waters. All these species are benthic, except for the cephalopod mollusc *Argonauta argo,* which is a pelagic species. As far as their ecological distribution is concerned, they are almost equally dispersed among soft and hard bottom communities. Thus, 67 species are distributed in hard substrate (see Table VI.11).

The benthic taxa from hard bottom communities in the Hellenic waters are exploited in different ways (Table VI.10). The majority of taxa are exploitated in many ways (e.g. human food, fishing, baits, household utility, jewellery, industry, collections/museums), while Echinodermata and Ascidia have a rather narrower exploitation (e.g. human food, collections/museums) However, at a species level, 45 % of the total number of commercial value species (37 species) are edible organisms, thus being collected mainly for food. (Table VI.12).

The production of each hard substrate species collected from Hellenic waters is rather difficult to estimate. Table VI.13 includes the official facts available on the commercial species, as published

Table VI.11: *Common species (or taxa) per hard substrate community type in the Hellenic seas.*

Suppralittora	Midlittoral	Ports	Sciaphilic algae	Photophilic algae
Chthamalus depressus	*Actinia equina*	*Bowerbankia* sp.	*Agelas oroides*	*Arca noae*
Littorina punctata	*Amphithoe helleri*	*Balanus trigonus*	*Axinella*	*Anemonia viridis*
Melaraphe neritoides	*Apanthura corsica*	*Ciona intestinalis*	*Alvania mamillata*	*Aplysina aerophoba*
Patella lusitanica	*Chthamalus stellatus*	*Clavelina lepadiformis*	*Bittium latreilli*	*Bittium reticulatum*
	Hydroides elegans	*Halocynthia papillosa*	Caprellidae	
	Leptochelia savignyi	*Leptopsammia pruvoti*	*Elasmopus rapax*	
		Nemertea	*Megathiris detruncata*	*Ircinia* spp.
		Ophiodromus pallidus	*Microcosmus sabatieri*	*Modiolus barbatus*
		Sphaeroma serratum	*Modiolus adriaticus*	*Platynereis dumerilii*
		Styela canopus	*Spondylus gaederopus*	*Scoletoma funchalensis*

Source: *ANTONIADOU & CHINTIROGLOU, 2005.*

Table VI.12: *Benthic organisms with commercial interest in Hellenic waters and various ways of their exploitation.*

TAXA	MED	Hellenic seas	Hard Substrate	Food Source	Fishing	Household utility	Jewellery	Industry (Drugs, cosmetics etc.)	Collections/ Museums
PORIFERA	7	7	7			*		*	*
CNIDARIA	11	7	7	*			*	*	*
SIPUNCULA	1	1							
POLYCHAETA	5	5	1		*				
MOLLUSCA	200	74	36	*	*		*	*	*
CRUSTACEA	79	36	12	*					*
ECHINODERMATA	6	2	2	*					*
TUNICATA	6	3	3	*					
TOTAL	315	135	68	45%	8%	8%	6%	11%	22%

Table VI.13: *Benthic organisms with commercial interest in the Aegean Sea along with their common Hellenic and English names, exploitation modes [HF = Human Food, FB = Fishing Bait, IND = Industrial use (Drug production, Cosmetics), HSU = Household use, JWL = Jewellery, COL/MUS = Collections/Museums) and mean annual production over the decade 1990 to 2000 = M.AN. PRPD (official production data added where available). (continued)*

SPECIES	Common Greek/English Names	Exploitation modes: M.AN.PROD
PORIFERA		
Hippospongia communis (Lamarck, 1813)	Kapadiko/Honey comb	HSU, IND
Spongia officinalis adriatica Schmidt, 1862	Fino/Greek bathing sponge	HSU, IND
Spongia officinalis mollissima Schmidt, 1862	Melatia/Turkey cup	HSU, IND
Spongia agaricina Pallas, 1766	Afti tou Elefanta/Elephant ear	HSU, IND
Spongia nitens (Schmidt, 1862)	Lovosfougaro/Shiny sponge	HSU, IND
Spongia virgultosa (Schmidt, 1868)	Solinosfougaro/Finger sponge	HSU, IND
Spongia zimocca Schmidt, 1862	Tsimoucha/Leather sponge	HSU, IND
CNIDARIA		
Anemonia viridis (Forskal, 1775)	Kolitsianos/Snakelocks anemone	HF
Corallium rubrum (Linnaeus, 1758)	Kokino korali/Red or Sardinia coral	IND, JWL, COL/MUS
Gerardia savaglia (Bertolomie)	Mavro korali, Giousouro/Black coral	IND, JWL, COL/MUS
Eunicella cavoliniii (Koch)	Gorgonia	COL/MUS
Eunicella verrucosa (Pallas)	Gorgonia	COL/MUS
Eunicella singularis (Esper)	Gorgonia	COL/MUS
Paramuricea clavata (Risso)	Gorgonia	COL/MUS
MOLLUSCA		
Patella caerulea Linnaeus, 1758	Petalida/Rayed Mediterranean limpet	HF
Patella ferruginea Gmelin, 1791	Sideropetalida/Ferreous limpet	HF
Patella nigra (Da Costa, 1791)	Mavri petalida/Black limpet	HF
Patella lusitanica Gmelin, 1791	Stiktopetalida/Ristic limpet	HF
Patella ulyssiponensis Gmelin, 1791	Agriopetalida/Rough limpet	HF
Haliotis tuberculata lamellosa Lamarck, 1822	Afti tis thalassas/Lamellated haliotis	JWL, COL/MUS
Monodonta articulata Lamarck, 1822	Arthrotos trochos/Articulate monodont	HF
Monodonta turbinata (Born, 1780)	Trochos fraoula/Turbinate monodont	HF
Bolma rugosa (Lamarck, 1813)	Mati tis Panagias, Strovilos	JWL
Cerithium alucastrum (Brocchi, 1814)	Skaltsini tou Aigeou/Spicate cerithe	FB
Cerithium vulgatum Bruguiere, 1792	Skaltsini/Mediterranean cerithe	FB
Strombus persicus (Roeding, 1798)	Konos tis Persias	COL/MUS
Luria lurida (Linnaeus, 1758)	Gourounitsa/	COL/MUS
Argobuccinum olearium (Linnaeus, 1758)	Agkathotritonas/Oil-vessel triton	COL/MUS
Charonia tritonis variegata (Linnaeus, 1758)	Polychromos tritonas/Variegated triton	COL/MUS
Charonia lampas lampas (Linnaeus, 1758)	Tritonas/Knobed triton	COL/MUS
Phyllonotus trunculus (Linnaeus, 178)	Strompos/Banded murex	HF,FB,COL/MUS : 5tns/year
Stramonita haemastoma (Linnaeus, 1758)	Porphyra/Red-mouth purpura	HF
Mitra zonata Marryat, 1817	Mitra/Zoned miter	COL/MUS
Conus mediterraneus Hwass in Bruguiere, 1792	Konos	COL/MUS
Arca noae Linnaeus, 1758	Kalognomi/Naoh's ark	HF ; 15tons/year
Barbatia barbata (Linnaeus, 1758)	Agriomydo/Hairy ark	HF

(continued)

SPECIES	Common Greek/English Names	Exploitation modes: M.AN.PROD
Lithophaga lithophaga (Linnaeus, 1758)	Petrosolinas/European date mussel	HF
Modiolus barbatus (Linnaeus, 1758)	Chavaro/Bearde horse mussel	HF : 8tns/year
MOLLUSCA		
Mytilus galloprovincialis Lamarck, 1819	Midi/Mediterranean mussel	HF : 280tns/year
Pteria hirundo (Linnaeus, 1758)	Fterostrido/European wing oyster	COL/MUS
Pinctada radiata (Leach, 1814)	Margaritoforo stride/Rayed pearl oyster	JWL, COL/MUS
Chlamys varia (Linnaeus, 1758)	Kalogria/Variegated scallop	HF
Chlamys multistriata (Poli, 1795)	Grammoto chteni/Little bay scallop	HF
Flexopecten glaber (Linnaeus, 1758)	Gialistero chteni/Smooth scallop	HF
Spondylus gaederopus Linnaeus, 1758	Gaidouropodaro/European thorny oyster	HF, COL/MUS
Ostrea edulis (Linnaeus, 1758)	Stridi/European flat oyster	HF ; 661tns/year
Crassostrea gigas (Thunberg, 1793)	Portogaliko stridi/Giant cupped oyster	HF
Crassostrea virginica (Gmelin, 1791)	Amerikaniko stridi/American cup oyster	HF
Pholas dactylus Linnaeus, 1758	Daktilo/Common paddock	HF
Octopus vulgaris Cuvier, 1797	Chtapodi/Common octopus	HF : 1020tns/year
CRUSTACEA		
Palaemon serratus (Pennant, 1777)	Garidaki/Common prawn	HF, FB
Homarus gammarus (Linnaeus, 1758)	Astakokaravida/European lobster	HF
Palinurus elephas (Fabricius, 1787)	Astakos/Common spiny lobster	HF, COL/MUS : 25tns/year
Scyllarides latus (Latreille, 1803)	Lira/Mediterranean locust lobster	HF
Scyllarus pygmaeus (Bate, 1888)	Astakoudaki/Pygmy locust lobster	HF
Paguristes oculatus (Fabricius, 1775)	Kavouras erimitis	FB
Diogenes pugilator (Roux, 1829)	Diogenis o erimitis	FB
Clibanarius erythropus (Latreille, 1818)	Kokinos erimitis	FB
Dromia personata (Linnaeus, 1758)	Patata/Sleepy crab	HF
Maja squinado (Herbst, 1788)	Kavouromana/Spinous spider crab	HF
Maja crispata Risso, 1827	Mikri kavouromana/Lesser spider crab	HF
Eriphia verrucosa (Forskal, 1775)	Petrokavouras/Warty crab	HF
ECHINODERMATA		
Arbacia lixula (Linnaeus, 1758)	Achinos/Stony sea urchin	HF
Paracentrotus lividus Lamarck, 1816	Achinos/Stony sea urchin	HF : 700tns/year
ASCIDIA		
Microcosmus polymorphus Heller, 1877	Vrachofouska/Rock violet	HF
Microcosmus sabatieri Roule, 1885	Fouska/Sea fig	HF : 3tns/year
Styella plicata (Lesueur, 1823)	Patata tis thalassas/Sea potato	HF

by the National Statistical Service and the ETANAL (Company associated with the Hellenic Ministry of Agriculture and recording production from 12 different fish auctions located in various areas of the Hellenic seas). However, official facts are available for 12 of the 67 species included in Table VI.13, and these are also limited. At first, the mean annual production of marine species collected with various fishing tools in the Aegean (148 species or aggregate of species of fishes and invertebrates), over the period 1990-2002 was 80 000 tonnes. Among the exploited species, 30 (20.3% of the total commercially exploited species) belong to different groups of invertebrates (molluscs, crustaceans, echinoderms, ascidians) and the mean annual production of these species is 7 000 tonnes (less than 10% of the total fisheries production). Twelve of these invertebrate species are distributed in the hard substrate (less than 10% of the total number of commercial value marine organisms in the Aegean Sea) and the most important taxonomic groups in which these species belong are the molluscs and the crustaceans. Despite the small number of the hard substrate invertebrate organisms exploited in the Aegean Sea and the fact that their total production/year is rather small (3 000 tonnes/year), their economic value is considerable (over 17 million EURO/year).

MENACES OF BENTHIC COMMUNITIES

The hard substrata communities are very sensitive because of their structural and functional complexity, their high productivity and also their position in the food web (primary and secondary consumers). Certain processes and activities have a negative impact on rocky bottoms, such as eutrophication, species introduction and invasion, effluents - liquid or solid wastes (terrigenous waters, domestic and industrial discharge, toxic substances, etc.), coastal engineering (breakwaters, seawalls, docks, harbours, dredging, etc.) species collection (for both commercial and aesthetic reasons), sports and recreation (SCUBA diving, spear-fishing, anchoring), etc.

Increased organic load is the greatest menace for hard substrate communities, leading to decreased water clarity and phytoplankton blooms. The community structure is strongly modified, as only tolerant species can survive (most of the filter-feeder species are affected by silt blocking their branchial apparatus). As a result, biodiversity is severely reduced and the biotopes become simplified. Thus, several biotopes are heavily modified (e.g. the Thermaikos and Saronikos gulfs), while the majority still maintains a good ecological status (e.g. the Chalkidiki Peninsula and most of the islands). Integrated management plans and actions to preserve benthic communities, in accordance with international directives, are essential before an irreversible degradation of these biodiversity rich biotopes occurs.

VI.6. CONSERVATION OF THE HELLENIC MARINE BIODIVERSITY

The marine and coastal ecosystems of Hellas, characteristic of the Mediterranean Sea, include all the representative Mediterranean habitat types, as its topography and bathymetry is very variable. A main characteristic of the Hellenic marine environment is the high habitat diversity encountered over small distances. Horizontally, rocky shores alternate with small sandy beaches and smaller or larger estuaries, while vertically, shallow waters change abruptly to deep waters.

Apart from specific coastal areas where the concentration of human activities has caused disturbance to the marine environment, the Hellenic Seas retain characteristics of high ecological quality. Measures to minimise human impact such as the application of restrictions on waste disposal or the prevention of overfishing, need to be combined with measures to conserve the most sensitive and important habitats and species.

The creation of protected areas promotes the development of activities that are compatible with nature protection in a broader area. Specific aims are: the protection of coastal and marine ecosystems especially those of European importance; the protection of sustainable fisheries and the marine ecosystems that support them; the protection of the populations and habitats of endangered marine species; the protection of endangered avifauna, especially migratory avifauna; the promotion of public awareness and sustainable tourism; the safeguarding of traditional activities and the conservation of natural and cultural landscapes.

HISTORICAL PERSPECTIVE

The earliest measures taken to conserve elements of the coastal and marine environment included restrictions on the use of certain fishing gear such as the otter trawl, in enclosed bays and inshore waters, as well as the ban on destructive fishing methods such as the use of dynamite. The first piece of legislation that included measures to protect marine species was the Presidential Decree 67/1981 that included 8 invertebrates, 12 fishes, 3 reptiles and 5 mammals. Hellas also ratified in 1983 the Bern Convention that included a number of marine species (32 invertebrates, 25 fishes, 3 reptiles, 13 mammals and a large number of waders and marine birds).

The first protected area that was set aside mostly for the protection of the marine environment was the National Marine Park of Alonnisos – Northern Sporades, where a large number of the critically endangered Mediterranean monk seal *Monachus monachus* lives. A second national marine park was later established in Zakynthos, mainly in order to conserve the nesting beaches of the loggerhead turtle *Caretta caretta* (Boxes 1 and 2).

MARINE AND COASTAL PROTECTED AREAS

A major breakthrough in the protection of marine and coastal areas in Hellas came with the provisions of the EC HABITATS Directive. One hundred and eleven out of the 239 sites (44.6 %) that were proposed by Hellas as Sites of Community Interest (SCI) include marine habitat types. In addition, eight sites that do not include any marine habitat should be taken into account as they contain sea cliffs and sea caves that are important for marine animals such as the Mediterranean monk seal. About a dozen more sites, not included in the SCI list, that are important for marine bird conservation were included in the list of Special Protected Areas (SPA) of the EC Birds Directive.

In most cases, the marine part of the protected sites extends offshore to a depth of 50 m, which is considered as the usual lower limit for the distribution of Mediterranean endemic *Posidonia* beds. In an attempt to evaluate the degree of importance of the marine environment, the sites with a marine component are assigned to nine categories (Figure VI.43) according to the objective of protection as shown in DAFIS *et al.*, (1996). The

Box 1: *The National Marine Park of Alonnisos-Northern Sporades*

The park (Figure VI.41), one of the largest protected areas in the Mediterranean Sea, is situated in the northern Aegean Sea and extends to 2 200 km^2 with a perimeter of 180 km. It comprises the island of Alonnisos (62 km^2), the only inhabited island in the park (2 800 inhabitants), nine smaller non-inhabited islands and a number of rocky islets. The park comprises three protection zones: the core, i.e. Piperi Island and 3 nm around it (70 km^2), and two other zones with different restrictions on human activities (1 480 and 650 km^2).

The marine environment includes extended open rocky shores and small coves with pebbles or sand. Extensive *Posidonia* beds cover the shallow sandy bottoms. Nevertheless, the greatest part of the marine environment extends to waters deeper than 200 m (maximum depth surpasses 1 000 m).

In addition to the highly endangered Mediterranean monk seal, *Monachus monachus*, other important species of the park include the Gioura wild goat *(Capra aegagrus dorcas)*, Eleonora's falcon *(Falco eleonorae)*, Audouin's gull *(Larus audouinii)*, the shag *(Phalacrocorax aristotelis),* Bonelli's eagle *(Hieraaetus fasciatus)* and the red coral *(Coralium rubrum)*. Also, several species of cetaceans have been reported, such as the striped dolphin *(Stenella coeruleoalba)*, the short-beaked common dolphin *(Delphinus delphis)*, Cuvier's beaked whale *(Ziphius cavirostris)* and the sperm whale *(Physeter macrocephalus)*.

Source: *www.alonissos.gr*

Figure VI.41:
The National Marine Park of Alonnisos-Northern Sporades

In spite of the fact that scientific surveys have been conducted only sporadically, the unspoiled marine environment of the park is reflected in its animal diversity: 175 species of megafauna, 407 species or higher taxa of macrofauna and 122 species of fish have been recorded so far (THESSALOU-LEGAKI, 1997).

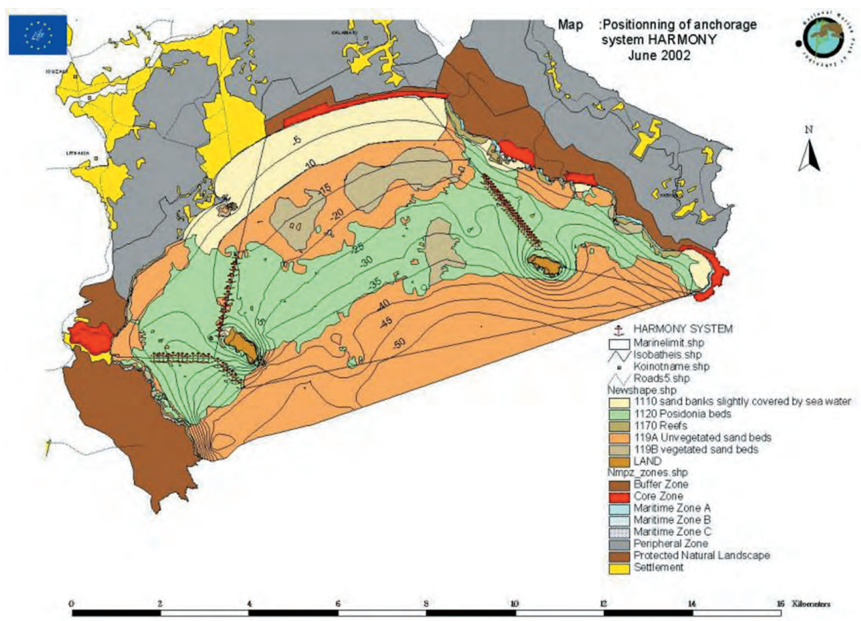
The park was established in 1992, but the Management Agency was only recently set up (2003). In the meantime, the management gap was covered mainly by the conservation efforts of a Hellenic NGO, Mom (Society for the Study and Protection of the Monk Seal), which, since 1993, has undertaken the implementation of guarding, monitoring and public awareness in collaboration with the Hellenic authorities.

During this period, systematic monitoring of the area resulted in the recording of 36 cave shelters for the Mediterranean monk seal. More than 3 000 visits revealed the existence of continuous reproductive activity over the years, with an average of six newborns per year. Until now about 55 individuals have been identified (in an estimated Mediterranean population of 200-250 animals). Also, in the rehabilitation facilities on the island of Alonnisos 11 newborns that encountered severe life threats were given medical treatment; seven of them were afterwards released in a healthy state into their natural environment.

Box 2: *The National Marine Park of Zakynthos*

The Bay of Laganas (Figures VI 42) on the island of Zakynthos hosts the most important known nesting aggregation of the loggerhead sea turtle *(Caretta caretta)* in the Mediterranean. An average of 1 300 nests per season are recorded on six beaches (Gerakas, Dafni, Sekania, Kalamaki, East Laganas and Marathonisi) having a total of 5.5 km in length, which hold some of the world's highest loggerhead nesting densities as documented by the studies carried out by Archelon, the Sea Turtle Protection Society of Hellas, since 1982. It is worth noting that as the beach of Sekania hosts over 50 % of the nests in the Bay, private land behind the beach was acquired by WWF-Greece in 1994 in order to ensure complete protection.

Due to the significance of Zakynthos as a sea turtle nesting ground and the threats it faces from increasing tourism pressure, the nesting beaches have been protected by law since 1984. In December 1999 the National Marine Park of Zakynthos was established after years of deliberations.



Source: *http://nmp-zak.org*

Figure VI.42: *Habitat types and bathymetry in the marine area of the National Marine Park of Zakynthos.*

Reflecting the complexities of land use and human activities, the park comprises a high number of zones: 7 terrestrial core zones and 4 buffer zones with a total area of 1 471 ha, and 2 maritime zones with a total area of 8 918 ha. There is also a peripheral area with 7 terrestrial zones (with a total area of 3 071 ha), acting as a transition stage to the main area of the park.

The marine protected area of Laganas Bay extends down to about 60 m. Soft bottoms predominate, hosting extensive *Posidonia oceanica* beds. In the bare sandy bottoms, 245 species or higher taxa of macrozoobenthic species have been reported, with increasing diversity and abundance as depth increases (THESSALOU-LEGAKI, unpublished data).

In addition to the Laganas Bay, the islands of Strofadia and the surrounding coastal waters within a radius of 500 m are also part of the National Marine Park of Zakynthos. These small islands are an important stopover for migratory avifauna and are located about 50 nm off the island of Zakynthos.

relative majority (31 %) of the sites with a marine component have been designated primarily because of their terrestrial importance. Thus, the marine area contributes only slightly to their total area. Another significant number of sites (20%) contain all or most of the terrestrial part of small islands of the Aegean and the Ionian seas as well as the surrounding marine environment. Of the remaining sites, lagoons and estuaries are transitional ecosystems leaving, consequently, only a small number of sites designated especially for the protection of the marine environment, i.e. coastal areas (8%), exclusively marine sites (12%), bays (4%) and extensive marine areas (2%). The latter are represented by the National Marine Park of Alonnisos-northern Sporades in the north Aegean (220 000 ha) and the inner archipelago of the Ionian Sea (88 000 ha). Although the sites with marine components are equally distributed all over continental and insular Hellas, there is a clear geographical differentiation between the above categories: large lagoons and estuaries are mostly found in northern continental Hellas.

Seven habitat types belonging to the Open Sea and Tidal Areas category of the Habitats Directive have been recorded so far in Hellas (Figure VI.44).

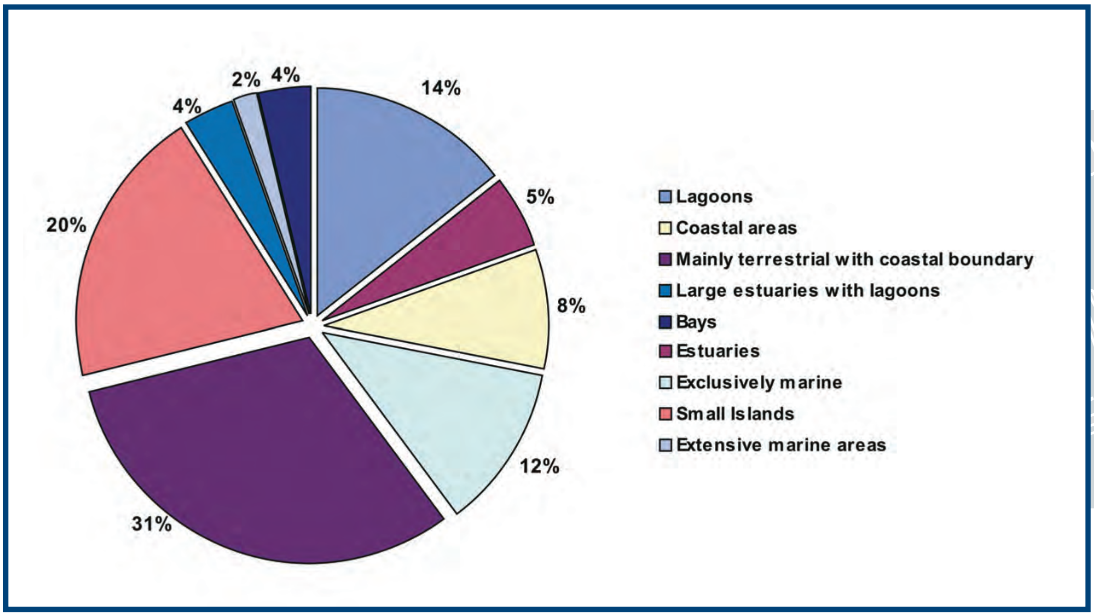


Figure VI.43: *Proposed Sites of Community Interest with a marine component (N = 111) according to the objective of protection. Data from DAFIS et al., 1996.*

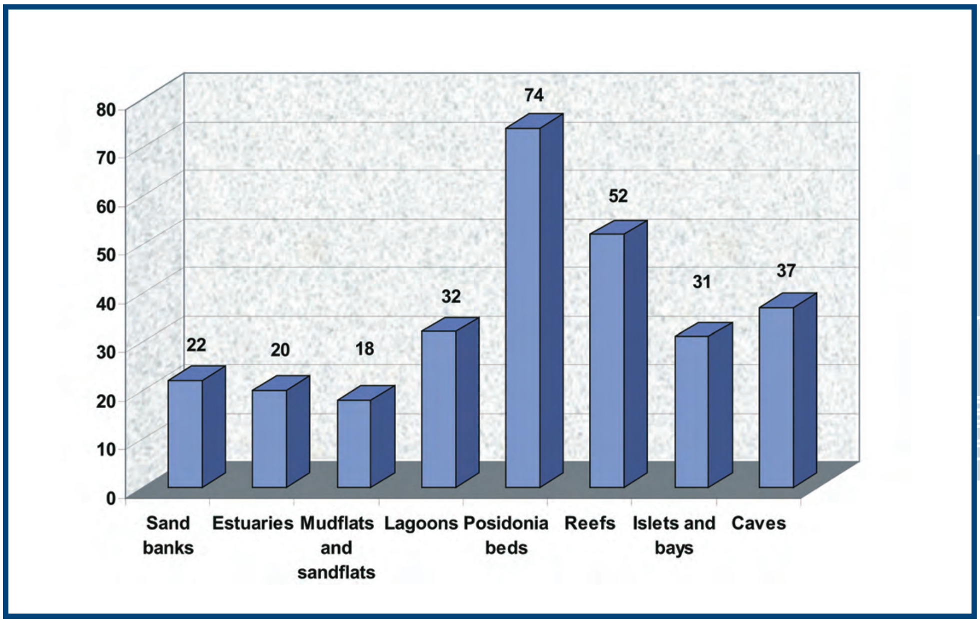


Figure VI.42: *Habitat types belonging to the Open Sea and Tidal Areas category of the Habitats Directive recorded from Hellas. Data from DAFIS et al., 1996.*

To these, we must include the habitat type of submerged or partly submerged sea caves. By far the most frequent habitat type encountered in SCI areas is the *Posidonia* beds followed by reefs.

With the exception of the two above-mentioned national marine parks (Boxes 1 and 2), management measures for the remaining sites are now starting to be implemented. Only recently (mid 2003), the Boards of the Management Agencies, were established by the Ministry of Environment in 27 NATURA 2000 sites, 14 of which are of marine importance. The Boards will work closely with the local authorities, competent Ministries, NGOs and other stakeholders in order to ensure the proper management of the sites. Objectives relevant to the marine environment include the control of visitors on the beaches, eco-tourist activities, public awareness, management of marine natural resources and control of pollution threats, law enforcement, monitoring and promotion of scientific research.

CONSERVATION OF MARINE SPECIES

The existing legislation for the conservation of marine species includes the Presidential Decree 67/1981, the EC Habitats Directive 92/43, the Bern Convention, the Bonn Convention on Migratory Species and the Convention on International Trade of Endangered Species (CITES). The Protocol of the Barcelona Convention (Convention for the Protection of the Marine Environment and the Coastal Regions of the Mediterranean) concerning Specially Protected Areas and Biological Diversity in the Mediterranean is also relevant, however, Hellas has not yet ratified it.

The species encountered in Hellenic marine and brackish habitats that are under legal protection are presented in Tables VI.14, VI.15 and VI.16. In general, 261 animal (of which 150 are birds not included herein) and 11 plant species (Table VI.16) are under some type of legal protection.

In recent years, several assessments of the conservation status of Hellenic marine species have been carried out by international organisations such as IUCN, and by Hellenic and foreign researchers. The results are summed up in Tables VI.14 & VI.15. It is evident that many threatened species are not protected by legislation, a fact that actually applies for all the Hellenic fauna (LEGAKIS, 2005). In addition, the population status for the majority of the protected species is not sufficiently known. The major constraints in applying legislative measures include the lack of public awareness and of appropriate training of the competent authorities.

Measures and implementation

The Presidential Decree for the establishment of the Park instituted a number of measures for the protection of the monk seal and the marine and terrestrial biodiversity. In zone A (strictly protected, 1 584 km^2) such measures include the permanent or seasonal prohibition of access on and around certain islands, and a permanent prohibition of middle-sized otter-trawlers and purse seiners as well as amateur fishing. In zone B (protected area, 678 km^2), which consists of the inhabited Island of Alonnisos and two nearby islands, there are hardly any restrictions for visiting the area and amateur fishing. However, middle fishing prohibition still applies to this region.

The implementation of fishing regulations seems to be effective mainly due to the fishermen's positive attitude. On the other hand, guarding of the park, although effective when applied especially during the tourist summer season, is not presently carried out on a regular basis due to financial and administrative reasons. The activation of the local Management Agency is expected to enhance the involvement of the local population through cooperation in order to promote the aims of conservation and human welfare.

Table VI.14: *List of threatened and / or protected marine and brackish-water vertebrate species reported from Hellas and relevant legislation.**

	A	B	C	D	E	F	G	H	I	J
MAMMALS										
Balaenoptera acutorostrata	IV		II		LR		I/A		II	
Balaenoptera physalus	IV	+	II	R	EN	I/II	I/A	V	II	
Delphinus delphis	IV	+	II	VU			II/A		II	
Grampus griseus	IV		II	R	DD		II/A		II	
Megaptera novaeangliae	IV		II		VU	I	I/A	V	II	
Mesoplodon bidens	IV		II		DD		II/A			
Monachus monachus	*II/IV	+	II	EN	CR	I/II	I/A	E	II	
Phocaena phocoena	II/IV	+	II	R	VU	II	II/A	K	II	
Physeter macrocephalus	IV		II	R	VU	I/II	I/A		II	
Pseudorca crassidens	IV		II				II/A		II	
Stenella caeruleoalba	IV		II	VU	LR		II/A		II	
Tursiops truncatus	II/IV	+	II		DD		II/A		II	
Ziphius cavirostris	IV		II		DD		II/A		II	
REPTILES										
Caretta caretta	*II/IV	+	II	EN	VU		I/A	V	II	
Chelonia mydas	IV	+	II	EN	EN		I/A	E	II	
Dermochelys coriacea	IV	+	II	EN	EN	I	I/A	E	II	
FISH										
Acipenser naccari	II/V	+	II		EN				II	
Acipenser stellatus	V		III		EN					
Acipenser sturio	II/IV	+	II		CR		I/A	E	II	
Alosa caspia	II/V			EN						x
Alosa fallax	II/V		III		DD				III	
Alosa macedonica	II/V				VU					+
Anguilla anguilla									III	
Aphanius fasciatus	II		II		DD				II	
Atherina boyeri					DD					
Carcharhinus plumbeus					VU					
Carcharias (=Eugomphodus) taurus					EN					
Carcharodon carcharias			II		VU				II	
Cetorhinus maximus			II		VU				II	
Dalatias licha					VU					
Epinephelus marginatus			III						III	
Eudontomyzon hellenicus	II		III	V/ EN	VU					+
Heptranchias perlo		+								
Hexanchus griseus		+			VU					
Hippocampus hippocampus			II		VU				II	
Hippocampus ramulosus			II		VU				II	
Huso huso	V				EN					
Isurus oxyrinchus			III						III	
Knipowitschia goerneri				T	DD					+
Knipowitschia milleri				VU	DD					+
Knipowitschia panizzae	II				DD					
Knipowitschia (=Gobius) thessala			III	VU	VU			E		+
Lamna nasus			III		VU				III	
Mobula mobular		+	II						II	
Mycteroperca rubra					DD					
Pagrus pagrus					EN					
Petromyzon marinus			III						III	
Platichthys flesus		+								
Prionace glauca			III						III	
Proterorhinus marmoratus		+	III	L/ EN						
Raja alba			III						III	
Ruvettus pretiosus		+								
Salaria (=Blennius) fluviatilis			III							

(continued)

(continued)

	A	B	C	D	E	F	G	H	I	J
Sciaena umbra			III						III	
Sparisoma cretense		+								
Squatina squatina			III						III	
Syngnathus abaster			III		DD					
Thunnus alalunga					DD					
Thunnus thynnus					DD				III	
Torpedo nobiliana		+								
Umbrina cirrosa			III						III	
Xiphias gladius					DD				III	
Xyrichthys novacula		+								
Zosterisessor (=Gobius) ophiocephalus				III		DD				
Zu cristatus		+								

Source: *LEGAKIS, 1999.*
Note: For explanation of column headings see end of Table VI.15.

Table VI.15: *List of threatened and / or protected marine and brackish-water invertebrate species reported from Hellas and relevant legislation.*

	A	B	C	E	G	H	I	K	L	M
PORIFERA										
Aplysina cavernicola			II				II			
Asbestopluma hypogea			II				II			
Axinella polypoides			II				II			
Hippospongia communis			III				III			+
Spongia agaricina			III				III			
Spongia officinalis			III				III			+
Spongia zimocca			III				III			+
CNIDARIA										
Antipathes subpinnata			III		II/B		III			
Astroides calycularis										+
Balanophyllia europaea					II/B					
Balanophyllia regia					II/B					
Caryophyllia calveri					II/B					
Caryophyllia inornata					II/B					
Caryophyllia schmithii					II/B					
Cladocora caespitosa					II/B					+
Corallium rubrum	V	+	III				III	+		+
Dendrophyllia carnigera					II/B					
Desmophyllum cristagalli					II/B					
Echinomuricea klavereni										+
Eunicella cavolinii										+
Eunicella singularis										+
Eunicella verrucosa						K		+		+
Gerardia savaglia			II				II			
Guynia annulata					II/B					
Hoplangia durothrix					II/B					
Leptopsammia pruvoti					II/B					
Lophelia pertusa					II/B					
Madracis pharensis					II/B					
Madrepora oculata					II/B					
Paracyathus pulchellus					II/B					
Paramuricea clavata										+
Paramuricea macrospina										+
Phyllangia mouchezii					II/B					
Polycyathus muellerae					II/B					
Stenocyathus vermiformis					II/B					
MOLLUSCA										
Acanthocardia aculeata										+
Acanthocardia echinata										+

(continued)

(continued)

	A	B	C	E	G	H	I	K	L	M
Acanthocardia tuberculata										+
Anomia ephippium										+
Arca barbata										+
Arca noae										+
Barnea candida										+
Callista chione										+
Chamelea (=Venus) verrucosa										+
Chlamys glabra										+
Chlamys opercularis										+
Chlamys varia										+
Donax semistriatus										+
Donax trunculus										+
Donax venustus										+
Ensis ensis										+
Ensis arquatus (=siliqua)										+
Glossus humanus (=Isocardia cor)		+								+
Laevicardium oblongum										+
Lithophaga lithophaga	IV		II				II	+		+
Mactra corallina										+
Mactra glauca										+
Mytilus galloprovincialis										+
Ostrea edulis										+
Paphia (=Venerupis) aurea										+
Pecten jacobeus										+
Pholas dactylus			II				II			+
Pinna nobilis (=P. rudis, P. pernula)	IV	+	II				II	+		+
Pisidium tenuilineatum									+	
Pteria hirundo										+
Solemya togota										+
Solen marginatus (=vagina)										+
Spisula subtruncata										+
Spondylus gaederopus										+
Tapes (=Venerupis) decussatus										+
Venerupis pullastra										+
Venus gallina										+
Acicula hausdorfi				DD						
Cassidaria echinophora										+
Cerithium vulgatum										+
Charonia rubicunda (=C. lampas, C. nodiferum)			II				II			
Charonia tritonis (=C. seguenziae)			II				II			
Cypraea lurida (= Luria)		+	II				II			
Cypraea pirum		+								
Cypraea spurca		+								
Dolium galea		+								
Erosaria spurca			II				II			
Gibbula nivosa			II				II			
Haliotis tuberculata										+
Littorina littorea										+
Mitra zonata			II				II			
Monodonta turbinata										+
Murex brandaris										+
Murex trunculus										+
Ocenebra erinacea										+
Ranella gigantea										+
Ranella olearia			II				II			
Tonna galea			II				II			
Triton nodiferus										+

(continued)

(continued)

	A	B	C	E	G	H	I	K	L	M
Vallonia enniensis				DD						
Zonaria pyrum			II				II			
CEPHALOPODA										
Argonauta argo		+								
BRYOZOA										
Myriapora truncata										+
Sertella beaniana										+
CRUSTACEA DECAPODA										
Callinectes sapidus										+
Cancer pagurus										+
Carcinus aestuarii										+
Homarus gammarus			III				III			+
Macropipus puber										+
Maja squinado			III				III			+
Nephrops norvegicus										+
Ocypode cursor			II							
Palinurus vulgaris (=P. elephas)			III				III			+
Scyllarides latus	V		III				III	+		
Scyllarus arctus			III				III			
Echinodermata										
Arbacia lixula										+
Asterina pancerii			II				II			
Centrostephanus longispinus	IV		II				II	+		
Ophidiaster ophidianus			II				II			
Paracentrotus lividus			III				III	+		+
Sphaerechinus granularis										+
TUNICATA										
Microcosmus sulcatus										+

Source: *LEGAKIS, 1999.*

Legend for Tables VI.14 & VI.15:
A: Council Directive 92/43/EEC.
B: Presidential Decree 67/1981.
C: Council of Europe, 1979. Convention on the conservation of European wildlife and natural habitats (Bern Convention)
D: KARANDEINOS M. (ed.) 1992.
E: IUCN, Species Survival Commission, 2003.
F: Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention, 1979)
G: Convention on International Trade in Endangered Species of Wild fauna and flora (CITES, 1973) Council Regulation EC 338/97.
H: Economic Commission for Europe,1991.
I: Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean (Protocol of Barcelona Convention), 1995.
J: Endemic Species or subspecies.
K: KOOMEN & VAN HELSDINGEN, 1993.
L: HASLETT , 1997.
M: HUNNAM, 1980.

I: Annex or Appendix I	T: Threatened species
II: Annex or Appendix II	L: Locally threatened species
III: Annex or Appendix III	CR: Critically endangered species
IV: Annex or Appendix IV	LR: Low Risk species
V: Annex or Appendix V	DD: Data deficient species
E, EN: Endangered species	*: Priority species for the European Union
V, VU: Vulnerable species	A: Species of Appendix A of the regulation applying CITES in the EC
R: Rare species	B: Species of Appendix B of the regulation applying CITES in the EC
K: Insufficiently known species	x: Species with endemic subspecies

Table VI.16: *List of Bern and Barcelona Convention marine plant species reported from Hellas.*

	Bern Convention	Barcelona Convention
MAGNOLIOPHYTA		
Cymodocea nodosa	+	
Posidonia oceanica	+	+
Zostera marina	+	+
Zostera noltii		+
PHAEOPHYTA		
Cystoseira amentacea	+	+
Cystoseira mediterranea	+	+
Cystoseira spinosa (inclus C. adriatica)	+	+
Cystoseira zosteroides	+	+
RHODOPHYTA		
Goniolithon byssoides	+	+
Lithophyllum lichenoides	+	+
Ptilophora mediterranea	+	+

VI. GAPS IN KNOWLEDGE - FUTURE PERSPECTIVES

- There are large gaps in our knowledge at **all levels** of biological organisation, including the basic biology and ecology of most marine and estuarine-lagoon species, life cycle, competence, sensitivity-tolerance and genetics.
- There is a lack of **synecological** scale-based understanding in all components of marine systems, where the relative 'importance' of species (e.g. dominant vs. keystone species) under different physical and chemical conditions is not known.
- There is a need to fill in gaps of **biodiversity** in unexplored geographic areas and habitat types e.g. hard bottom **zoobenthos** in the south Aegean Sea and reference habitats of the infralittoral are under explored. Also hard **bottom phytobenthos** in clean reference areas such as **photophilous** algae communities in the upper infralittoral, trottoir, coralligenous communities, etc., are scarce.
- **Lack of expertise** in several groups of zoobenthos (e.g. Nemertea, Oligochaeta, Foraminifera) and phytobenthos. Overall species diversity is believed to be a lot higher.
- **Meiofaunal** studies require the development of an array of new methods and techniques in experimentation and in the field in order to assess the spatial and temporal structure of meiofaunal communities, its importance in the benthic food web; on geochemical fluxes, on bioturbation and as sensors of environmental stress.
- Development of Long-Term Projects covering the need for assessing **temporal trends** and comparisons among anthropogenical impacted vs. naturally disturbed environments.
- Extending the scope of studies **beyond the level of species matrices,** incorporating more data on size, life cycle, trophic relations, productivity, ecophysiology and genetics, and developing Rapid Assessment Surveys (RASs) for the assessment of the Marine Environment.
- In **lagoonal** ecosystems a quantification of confinement based on physical descriptors and its relation to biological attributes is needed; a quantification of terrestrial input in terms of fresh water and nutrients; a study of the autecology of dominant species; an assessment of the economic significance of the lagoons
- Since marine **protected areas** are becoming an important tool for preserving biodiversity and for managing fisheries, there is an urgent need for studies to determine baseline information such as size, number and location in order to improve the efficiency of these areas. Also in the level of marine **protected species** an estimation of population status, threats and trends for the top-priority species is highly needed.
- **Networking:** joining forces, setting the essential questions, developing the National Strategy in compliance with EU and International Treaties and Conventions, linking with the relevant EU Networks (MARBEF, MARINE GENOMICS, etc.).
- Data archiving for all ecosystems/habitat types. **Dbase** development, central depository of data from the Hellenic Environment (MedOBIS under development).

More scientific training and capacity building is needed for carrying out the above activities. This requires, inter alia, an adaptation of Hellenic university curricula towards biodiversity and conservation issues.

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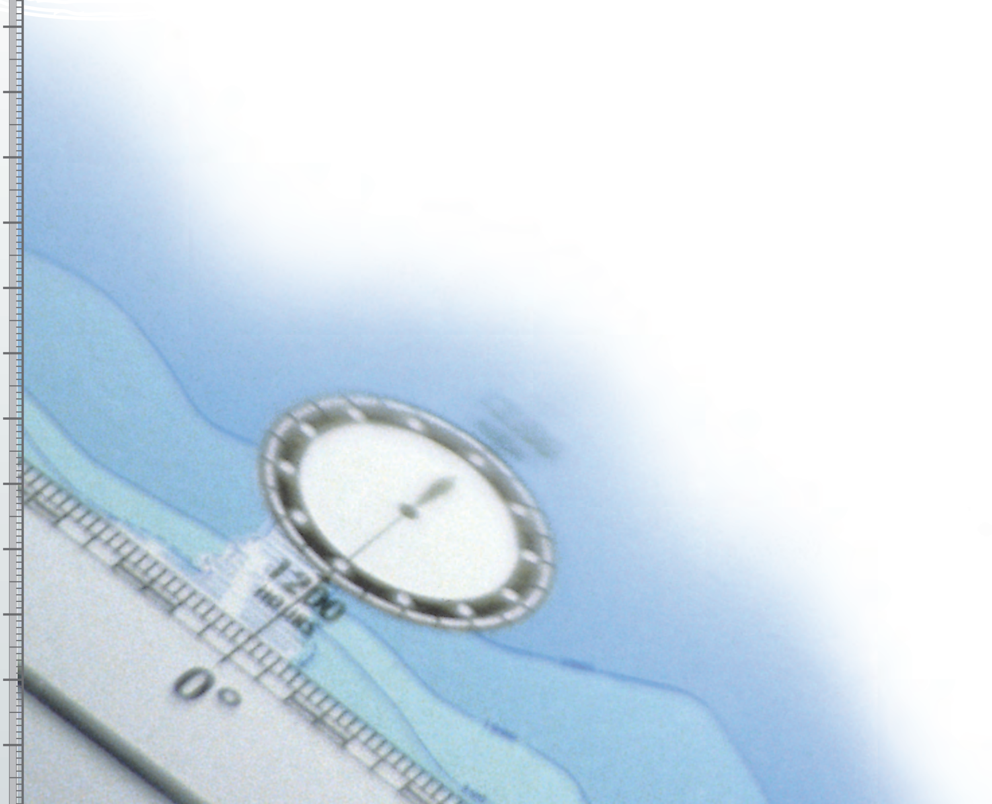
CHAPTER VII
EXPLOITATION OF LIVING RESOURCES



VII. EXPLOITATION OF LIVING RESOURCES

INTRODUCTION

The UNIT is split into three sections: fisheries, trophic position of fish in marine ecosystems and aquaculture.

The chapter on Hellenic fisheries introduces relevant information concerning the fisheries sector in Hellas. An important part of this section is devoted to describing the context of method applications and fishery considerations, whereas little information is given on the present status of the resources and their evolution during the reference period (usually up to 2000 when data is derived from FAO FISHBASE or 2004 when it is based on the national database). However, a new approach to assessing the health of fish communities appears to be the one based on the concept of the fractional trophic level. In this report, we present the mean weighed trophic levels of the marine fish catches from Hellenic waters. Trophic levels were mainly estimated from feeding studies, which have been reviewed by the authors based on data up to 2004.

Fishing has dramatic effects on marine ecosystems at all levels of biological organisation, namely individual, population and community-ecosystem. Effects of fishing and aquaculture activities at the community level are addressed under the section 'Anthropogenic Activities' where changes in the mean trophic level of the catches are also examined.

Aquaculture started in Hellas around 1980 with the significant aid of the EU structural funds. Nowadays, Hellas is the leader member state in the production of sea bass, *Dicentrarchus labrax*, and sea bream, *Sparus aurata*. Aquaculture is highly integrated and many farms own hatcheries, on-growing cage farms and processing plants, which ensure that the product reaches the consumer at the highest possible quality levels in accordance to the EU regulations. The development of the aquaculture sector since 1985 and a critical review of all aspects including the socioeconomic ones are treated in the last chapter of this section.

VII.1. THE HELLENIC FISHERIES

OVERVIEW AND MAJOR CHARACTERISTICS OF THE HELLENIC FISHERY SECTOR

Fishing is one of the oldest activities associated with the Hellenic people and culture. This ancient lineage signifies the strength of traditional ties and of deeply embedded social forms in the evolving structure and subsequent development of the fisheries sector.

The gross product value of the fisheries and aquaculture sector accounts for around 5.6% of the Gross Agriculture Product and around 1.0% of the Gross Domestic Product. Furthermore, the fisheries' sector share in total agriculture employment and in national employment is 3.5% and 1.2%, respectively. It must be pointed out that in a number of areas (usually small islands) employment in the fisheries' sector can reach up to 25 or 30 % of the area total. Thus, the Hellenic fisheries' sector, despite its relatively low contribution to the GDP, remains an important one, particularly in rural areas with intense socioeconomic problems such as in coastal and island communities (ANONYMOUS, 2000).

In general, the sector can be divided into three categories: (a) marine or capture fishery, (b) aquaculture, and (c) processing and marketing of products. The marine fishery category includes the professional fishermen who are the most numerous in terms of employment and the most important in terms of production volume. In the framework of the present paper only the marine fishery sector will be described.

Hellas is a Mediterranean country with a total coastline of about 15 000 km. The Hellenic marine fisheries' sector is characterised by this extended coastline, a large number of small islands and the fact that a high proportion of the coastal areas' employment is being absorbed by the fisheries' sector and its ancillary activities. The conditions, which are distinctive of the Hellenic marine fishery, are: (a) the extended length of the coastline, (b) the narrow continental shelf and slope, (c) the low biological productivity of the waters, (d) the great number of exploitable species, (e) the mostly- rocky nature of the bottom, and (f) the limited extent of grounds suitable for trawling.

Because of the presence of a relatively narrow continental shelf, fishing vessels are confined to operate over a narrow zone (usually, from one to three miles from the coast and rarely beyond four miles). The main area of operation of the Hellenic fishing fleet is the Aegean Sea, the gulfs of the mainland which are connected to this area, the northern coasts of the island of Kriti and the western coasts of the Peloponnisos (ANONYMOUS, 1994). The presence of deep waters in the Ionian Sea and the extremely narrow continental shelf around the islands do not favour the development of important fishing activities in the northwestern part of the country (PETRAKIS & PAPACONSTANTINOU, 1997).

The management of the Hellenic fisheries is in accordance with the Common Fishery Policy in effect, as well as the multi-annual guidance programs which aim:

- to improve the productivity of the fleet;
- to improve the welfare and quality of the fishing sector; and
- to promote the balanced and sustainable of the fisheries' resources supported by the centralised frameworks of support with the following main objectives:
  - the renewal and modernisation of the fleet;
  - the development of small scale fisheries;
  - the adjustment of the fishing effort;
  - the social and financial support of the fisheries sector.

Administrative classification of the Hellenic fishery

Marine fishery includes the professional fishermen who are the most numerous in terms of employment and the most important in terms of production volumes. According to the Hellenic administrative classification criteria (KOTSOLIOS, 1994) the national fishery sector is separated into three main sub-categories:

(a) 'small-scale fisheries', operating in coastal waters by vessels employing set gear (gill nets, trammel nets, surrounding nets, hook lines, longlines, traps, etc.) and also certain types of towed gear, such as dredges and beach seines;

(b) 'medium fishery' - operated by trawlers and purse-seiners; and

(c) 'transatlantic fishery' - operated by large trawlers fishing for fish and shrimps in the high seas. Within this sub-category a number of vessels are included that serve primarily as transporters of the products from the fishing area.

However, apart from the three officially recognised sub-categories, an additional one exists. It is the sport (recreational or amateur's) sub-category, which is a significant aspect of concern, particularly as it regards competition with the small-scale coastal fisheries.

Description of the Hellenic fishing fleet

The number of vessels of the Hellenic fishing fleet is decreasing over the last 13 years. On the 31 December 1991 the fleet comprised a total number of 22 237 vessels as compared to 20 594 vessels in 1996 and 18 836 vessels in 2003. The fishing fleet number distribution per geographical area (Aegean and Ionian Sea) is presented in Table VII.1. In Figure VII.1 it is obvious that this decrease arises from different levels of decrease in each fishing sub-category. Hence, in coastal fisheries this decrease was about 2% while in medium fisheries it reached 21% and in transatlantic fisheries it was 55%. The age distribution of the Hellenic fishing fleet per administrative area is given in Table VII.2. On the other hand, the total number of fishermen is rather steady, being 40 153 (mean number for the period 1991-1997).

Description of the Hellenic fishery production

The total Hellenic fishery production fluctuated between 90 000 and 160 000 tonnes over the last 15 years (Figure VII.2).

Main problems of the Hellenic fishery

The capture fisheries' sector presently faces significant problems, primarily based on the reasons briefly presented below:

(a) The large number of small, old and insufficiently equipped fishing vessels, with high operating costs rendering them as non-profitable enterprises (in most cases the working conditions are below the internationally accepted standards).

(b) The large number of employees, mainly older men, without any professional training.

Table VII.1. *Fishing fleet number distribution per administrative area.*

Vessel Number (per gear used)					
AEGEAN SEA	<12 m	12-24 m	24-40 m	>40 m	Totals
Trawlers		135	163		298
Purse Seiners	6	246	19		271
Coastal vessels	13 114	420			13 534
Atlantic vessels		8	26	11	45
Totals	13 120	809	208	11	**14 148**
IONIAN SEA					
Trawlers		29	9		38
Purse Seiners	3	43			46
Coastal vessels	4 556	49			4 605
Atlantic vessels	116	10			126
Totals	4 675	131	9		**4 815**

Table VII.2. *Age distribution (years since construction) of the Hellenic fishing fleet per administrative area.*

Segment	Aegean Sea	Ionian Sea
Trawlers	22.26	23.36
Purse Seiners	22.74	43.05
Coastal vessels	27.95	31.82
Atlantic	25.67	-

(c) The practice of fishing in coastal island areas where harsh competition exists for the exploitation of the available natural resources, a fact that has resulted in the degradation of the delicate coastal environment.

(d) The complete lack of, or insufficiently equipped, infrastructure facilities regarding fishing ports, supply services and marketing channels.

These characteristics along with a number of socio-economic aspects that have shaped the rural population during the second half of the 20th century have favoured the development of the multi-gear coastal fisheries. This fishery is composed of vessels, many of which are of reduced engine power, operating within the 100 m contour depth-line, which in many areas does not extend beyond the 1-mile zone. It is noteworthy that the 1-mile zone from the coast determines the boundary between the wider coastal fishery sector and medium fishery (conducted mainly by trawlers, not permitted to operate within that zone). However, since most of the national fisheries are conducted over the narrow coastal zone, vessels of different fishing categories often operate in the same fishing grounds, often creating tension between fishermen of different categories.

The resulting overexploitation of the Hellenic fishing grounds, as a result of the increasing demand for fishery products, has become an aspect of concern as the production trends show signs of fatigue and the quality of the catch is being reduced.

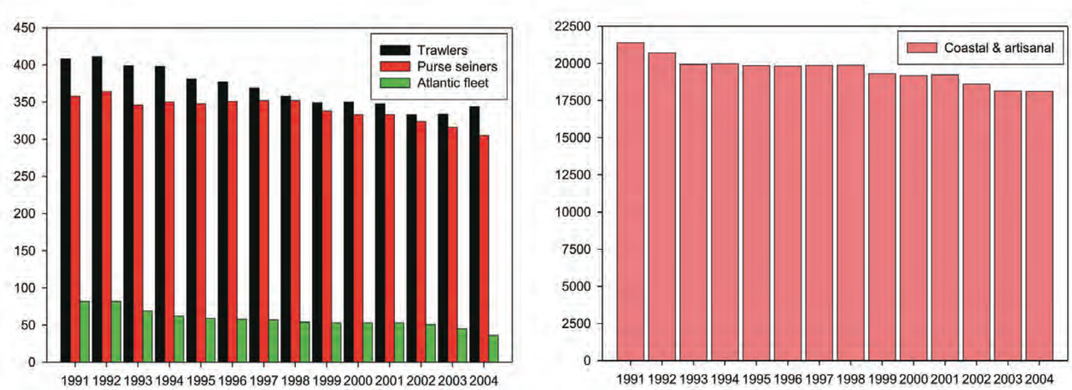


Figure VII.1: *The vessels (in number) in each fishing category from 1991 to 2004.*

Source: *Greek Centre for Excellence for Fisheries and Coastal Zone Management, Data Centre.*

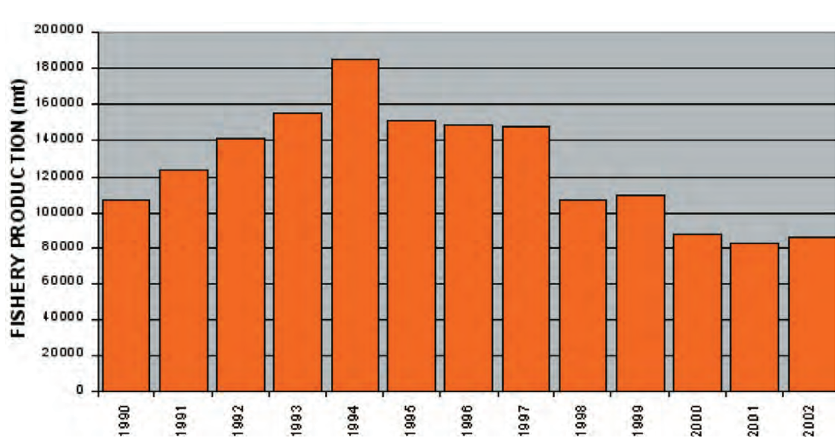


Figure VII.2: *The total sea fishery production of Hellas from 1990 to 2002.*

Source: *FAO Fishstat, 1950-2002.*

Finally, the degradation of the coastal environment due to the high urbanisation rate of the coastal areas and the intense competition for the resources, exert an additional negative influence particularly on the coastal fisheries' sector.

THE STATE OF THE RESOURCES

Periodical updating of the research activities dealing mainly with demersal and small pelagic Hellenic living resources and fisheries have been realised by GFCM (General Fisheries Council for the Mediterranean) since 1984, during working group occasions and technical consultations at a regional level (PAPACONSTANTINOU & FARRUGIO, 2000). The scientific knowledge of large pelagic stocks and fisheries is annually updated for more than ten years by ICCAT (International Commission for the Conservation of Atlantic Tunas).

Various research projects have been carried out in the Hellenic Seas during the last 20 years aiming towards the recording of the fish stock state. The EU with the partial contribution of the Hellenic government funded all these projects. The duration of these projects was not more than two years and thus, the spatiotemporal fluctuation of the stocks was not clearly realised. The only exception is the MEDITS programme (BETRAND *et al.*, 2002), funded from EU, France, Hellas, Italy and Spain, which was carried out along the north coasts of the Mediterranean Sea between 1994 and 2002. Fishery landings' trends can provide the only indication about important changes that might have occurred in the past.

Assessment of the most important commercial, demersal resources in Hellenic waters has been carried out by Hellenic scientists during the last years based mainly on experimental trawl surveys. A cohort analysis has been attempted for the hake stock in the north Aegean (PAPACONSTANTINOU *et al.*, 1991), as well as yield per recruit analyses have been carried out for different species e.g. hake and red mullet. From these studies a high exploitation rate has been calculated for the most commercial species, reinforcing the view that the stocks in the area are in a general state of full to overexploitation for several species. However, the geomorphology of the Hellenic Seas and the applied fisheries' management measures, which are based mainly on the closed areas and seasons, contributes to the different exploitation status of the species stock in the area. Major efforts in data collection are required to get a clear picture of the status of the key stocks, although indications based on current data paint an extremely negative picture.

Catch statistics on demersal and small pelagic species show a negative trend in the 1990s for the most important species or groups of species. Daily catch rates per vessel have fallen dramatically when compared to catch rates of some decades, despite the fact that the power and efficiency of fishing vessels has increased recently. Also the catch quality, both in terms of species and size composition, has changed over time. Long-life span species and bigger sized specimens have practically disappeared from demersal catches in several areas and fisheries.

Concerning small pelagic fishery it makes up a significant proportion of the catches along the coast of the north Aegean and in the Saronikos Gulf. The only fishing gear operated is the purse seiner. Mesopelagic trawling is prohibited in the area. Assessments of small pelagic resources have been carried out during the last years by acoustic methods and eggs and larvae mainly in the north Aegean Sea. A sharp decline of the anchovy stock has been noted in recent years in the Hellenic waters, whilst for the sardine stock there is no evidence of overfishing (Figure VII.3).

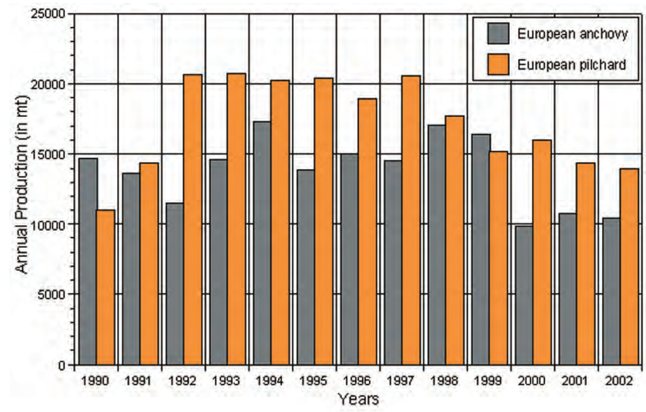
With regard to high migratory species, the Hellenic bluefin tuna stock has been assessed in the past by the ICCAT (International Commission for the Conservation of Atlantic Tunas), which has indicated heavy overexploitation. Although the thoroughness of these evaluations is arguable due to considerable uncertainties resulting from the lack of key data, there is little doubt that the stock is overexploited. Similar considerations on overexploitation apply to swordfish in Hellas where there is evidence of an exploitation pattern, which results in large quantities of juveniles and recruits of the year, present in the catches.

Fishing activity in Hellas was conducted down to 500 m depth until a few years ago (Figure VII.4). The main reason for not exploiting lower depths is the fact that the fishermen believe that fishing at such depths is not profitable or less profitable than fishing in shallow depths. Moreover, the fishermen are not willing to invest in the possibility to develop fisheries in deep waters because of the increased risk of losing the fishing gears and active fishing time (PAPACONSTANTINOU, 2002).

The extension of fishing in deeper waters is a new perspective for the development of Hellenic fisheries. This possibility has been the focus of interest of the scientific community and the European Commission has provided either scientific or structural support for deep-water fisheries. At the same time, problems related to the deep-water ecosystems became the focus of the scientific community considering that the knowledge of their organisation and function is essential for their rational fishery management. The most important deep-water stocks and in particular within the 500-1 000 m stratum, which are exploited in Hellas, are two species of red shrimps (*Aristeus antennatus* and *Aristeomorpha foliacea*) which are fished with trawls as well as the black-spot seabream (*Pagellus bogaraveo*), the hake (*Merluccius merluccius*) and the wreckfish *(Polyprion americanus)* which are fished mainly with long lines.

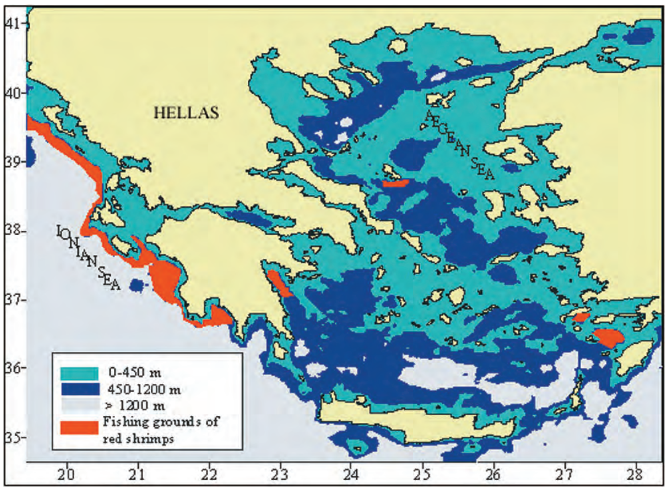
The main geographic area suitable for red shrimps is the continental shelf of the Ionian Sea (PETRAKIS & PAPACONSTANTINOU, 1997) while the significance of the Aegean Sea in this respect is much lower and focused in a few areas of the north Aegean and southeast Aegean. In any case, the

Figure VII.3:
Hellenic annual production of small pelagic species.



Source: *FAO Fishstat, 1950-2002.*

Figure VII.4:
Fishing Areas in Hellenic seas.



Source: *Greek Centre for Excellence for Fisheries and Coastal Zone Management, Data Centre.*

facts that unexploited demersal resources are scarce in the Mediterranean due to the high pressure of bottom trawling on almost all the available fishing grounds and that there is no fishing pressure on the Hellenic Ionian Sea red shrimp, suggests that it could constitute a fishery target having a new and potential perspective for the Hellenic fisheries sector.

The best solution for sustainable deep-sea fisheries may be to adopt practices similar to those for the black scabbard fisheries in Madeira (MARTINS & FERREIRA, 1995) or the red shrimp fisheries in the western Mediterranean (RAGONESE & BIANCHINI, 1995). Those fisheries are conducted by relatively small vessels operating locally and targeting on a small volume of high quality catch. PAPACONSTANTINOU & KAPIRIS (2003) reports that these features should be considered when developing a model for the management of the red shrimp fisheries in Hellas, taking into account the relatively limited engine power of the operating trawl vessels in the sea, as well as the rather restricted areas, where such fisheries could be operated. Also, the official closure of common trawl fishery in Hellenic waters during the peak of the giant red shrimp reproduction period might be relevant.

MANAGEMENT OF THE MARINE BIOLOGICAL RESOURCES

General view

The fisheries management and conservation policy is under the authority and responsibility of the Ministry of Agriculture. The legal framework for regulating all fisheries issues is provided by the Fishing Code (Law Decree 420/70). This decree is actually a compilation of previous laws concerning competent authorities, gear, vessels, fishing practices, fishing seasons, enforcement of discipline and procedures for the introduction or modifications of rules (Table VII.3). Since 1970, the Fishing Code has undergone only minor modifications and improvements, especially with regard to penalty levels and the mechanisms for modifying conservation measures (e.g. Law Decrees 1740/87 and 2040/92). Therefore, it could be stated that the Fishing Code of 1970 still forms the basis of the current Hellenic fisheries legislation.

Within the Common Fisheries Policy (CFP), the structure and market policies have been applied and enforced in the Mediterranean in an equivalent manner to other Community areas. This is also the case for the control policy, although the implementation of some aspects of the control

Table VII.3: *Fisheries regulation and enforcement in Hellas.*

Fishery regulations	
Vessel licensing	Yes
Mesh-size regulations*	Yes
HP limits of the fishing vessels **	Yes
Closed seasons for fisheries	Yes
Closed areas for fisheries	Yes
Depth limit for trawlers, purse and beach seiners	Yes
Trawl cod end (stretched mesh size)	Yes - 40mm
Beach seine stretched	Yes - 18 mm
Purse seine stretched	Yes - 28 mm
Distance from coast (beach seiners)	70 m
Distance from the coast (trawl fishery)	3 miles
Distance from the coast (purse seiners)	100 m
Closed seasons for trawl fleet and beach seiners	June-September
Closed seasons for swordfish drift-longlines	1st October-31st January
Closed season for purse seine fleet	December-February

Notes: * including coastal fisheries, ** trawlers and purse seiners.

Source: *Ministry of Agriculture Development and Food.*

policy has been delayed in the Mediterranean. However, the conservation policy has traditionally been carried out differently than in the other areas

Surveillance and the prosecution policy are under the authority of the Ministry of Merchant Navy Marine. The responsibility for controls and enforcement of discipline has been transferred to the patrol services (port authorities/ coastguard), which are located in all important navigational and fisheries ports of the country, and fall under the same Ministirial jurisdiction.

Management and conservation rules

The Hellenic fisheries legislation contains a great variety of conservation/management measures which can be broadly separated into two major categories: (1) those aiming to keep fishing efforts under control, and (2) those aiming to rationalise the exploitation of the resources. The first set of measures contains restrictions on the number or fishing capacity of the vessels. The second set of measures contains provisions of gear, fishing practices and fishing areas or seasons and are commonly known as technical measures. The Hellenic legislation does not contain provisions on discards or by-catches and catch limits (TACs), except on tuna fisheries, which are extensive and apply to the Atlantic.

Measures controlling fishing effort

Measures restricting effort were gradually introduced during the evolution of the Hellenic fisheries policy. Some of these measures aim at controlling the number of fishing vessels, through a licensing system, and can be characterised as direct measures. Other measures aim at controlling the fishing capacity of individual vessels, through engine power and tonnage limitations, and can be characterised as indirect. Note that the Hellenic management system does not include limitation on amount of catches or gear and on time spent fishing (e.g. length of nets, number of hooks per longline on board, catch limits, number of exits or duration of fishing expeditions, etc).

(a) Coastal fisheries

Up to 1998, there were no restrictions on the issue of licences for coastal fishing vessels, except for beach-seiners. As far as other segments of the coastal fishing fleet are concerned, until restrictive measures were enforced, there was a steady increase in the number of fishing units. The restrictions on fishing licences for coastal fishing vessels were introduced in 1988 and had an immediate inhibiting effect on the rate of increase of the fleet. Indeed, the average rate of increase between 1988 and 1990 dropped to about 2.6% per year.

In line with the MAGP, a restructuring programme for coastal fisheries has been designed, based on permanent withdrawals, new constructions and a limited number of modernisations. The objective was to reduce the fishing effort of the segment of the fleet, of the vessels with length less than 12 m, by 3.6% in terms of engine power and tonnage by the year 2001. The objectives of the MAGP for the year 2001 were satisfied.

(b) Medium fisheries

A limited entry scheme for the medium fisheries was introduced in 1986. This scheme has generally been effective, preventing the uncontrolled increase of the number of vessels. A complete prohibition of the issue of new licences has been enforced in 1988. However, the total engine power and tonnage of the medium fisheries' vessels has increased significantly since then, due to modernisation and reconstruction of such vessels, especially so after the middle of the 1980s. In addition to the limited entry scheme, capacity limitations for both trawlers and purse-seiners also exist. Trawlers are not allowed to have an engine power higher that 500 HP and purse-seiners are not allowed to have an engine power higher than 300 HP.

In line with the MAGP, a long-term management objective to reduce the fishing effort of trawlers by 20% has been established. These objectives have also been satisfied (2004).

Measures controlling fishing activities (Technical measures)

The technical measures comprise an important part of the Hellenic management/ conservation system. Such measures may deal with gear specification, gear deployment, fishing techniques and fishing seasons and areas. However, in the absence of adequate results from scientific investigations on spawning or nursery grounds, maturation sizes, mesh selectivity studies, etc.; the adequacy, effectiveness and suitability of many of these measures have yet to be verified.

As Hellas has not defined an Exclusive Zone, the technical measures are applicable for the fishing activities conducted in the territorial waters (6 miles). Note, however, that in most regions, fishing is practically restricted within the six-mile zone due to the extremely narrow continental shelf and slope.

The existing technical measures can be separated into nationwide and local. As the names imply, the first have a general applicability over the whole country, while the second concern a specified geographical area. Almost all measures refer to particular gear or fishing techniques except those concerning minimum landing sizes, which apply to all gear.

(a) Coastal fisheries

For the majority of the coastal fleet, which consists mainly of bottom netters and longliners, there are no important nationwide restrictions, except those concerning landing sizes. Thus, there are no nationwide regulations on mesh size or hook size, distance from shore or from homeport, depth of fishing, seasonal or geographical prohibitions of fishing, etc. However, there is a general prohibition of certain gear throughout the country (e.g. midwater trawls, drift nets, nylon nets and small surrounding nets). There is also a general ban of some gear in estuaries, mouths of lagoons, other ecologically sensitive zones and ports, as well as some minor restrictions on gear deployment, such as in the production of noise in order to drive fish towards the nets.

For some specialised branches of the coastal fisheries, more severe nationwide limitations exist. Thus, there is a general ban on fishing with beach-seiners from the 1st of June to the 30th of September, and on fishing for swordfish with drift-longlines from 1st October to 31st of January.

(b) Medium fisheries

The medium fisheries sector is subject to more severe restrictions in comparison to the coastal fisheries. Under the national legislation, demersal trawling is generally prohibited during the summer period (from 1st June to 30th September) and within the one mile coastal zone (in river estuaries, the trawling prohibition is three miles from the shore). In some regions, the seasonal ban is longer and can reach up to six or nine months. Some gulfs or sections of these are permanently closed to trawl fishery.

Under the provisions of article 3, part 1, of Council Regulation 1626/94, the prohibited fishing zone for trawlers, has recently been extended to three miles in all areas. Trawl fishing is also prohibited within the 50 m depth contour line. Under article 6, part. 1 of Council Regulation 1626/94, a minimum trawl bag mesh size of 40 mm stretched has been introduced, which is much higher than the 28 mm mesh size provided under current national rules.

For purse-seiners, a seasonal fishing prohibition (from the beginning of December to the end of February) was introduced in 1991. In addition, for purse-seiners operating at night, fishing is prohibited within 100 m from the shore or within the 30 m depth contour line. The allowed minimum mesh size is 14 mm for night purse-seiners and 40 mm for day purse-seiners.

VII.2. THE TROPHIC POSITION OF FISHES IN HELLENIC MARINE ECOSYSTEMS

In recent years, new approaches allow fisheries research to be put in an ecosystem framework. Such approaches are either based on, or make use of, the fractional trophic level - henceforth called trophic level (for definition and estimation see Box 1) of the species embedded in marine ecosystems. They include among others: (a) the estimation of the 'primary production required' to sustain fisheries (PAULY & CHRISTENSEN, 1995); (b) the 'fishing down the marine food webs' hypothesis, which refers to the decline in the mean weighed trophic level of catches (and communities) with time because fishing removes the largest individuals that are generally positioned higher in the food webs and allows us to identify the effects of fishing on marine ecosystems (e.g. PAULY *et al.*, 1998a); (c) the comparative community analysis (PAULY *et al.*, 2000a); and (d) fisheries-oriented ecological modelling (e.g. PAULY *et al.*, 2000b).

The trophic level concept has important managerial implications. It is becoming clearly understood that trophic level balance is an objective, related to clearly defined indicators (e.g. aggregate annual removals from each trophic level) and reference points (e.g. maximum % annual removals) (GISLASON *et al.*, 2000).

In this report, we present the trophic levels of the marine fishes from Hellenic waters, as estimated from feeding studies, based on data assembled by STERGIOU & KARPOUZI (2002) and updated with information published thereafter (Figure VII.5).

AVAILABLE FEEDING STUDIES

Overall, 111 data sets [those reviewed by STERGIOU & KARPOUZI (2002) and updated with 15 new datasets] on the diet of fishes in the Hellenic Seas, were collected from the literature. These refer to 58 species, 27 families and 10 orders. The maximum reported body size of the 58 species

Box 1: ***Trophic level: definition and estimation***

The trophic level expresses the position of a species in a marine food web, thus quantifying its role in the ecosystem (PAULY & CHRISTENSEN, 2000). Its estimation requires knowledge of what a species feeds on and in what quantities (i.e., the relative abundance of each prey participating in the diet). In this case, the trophic level can be calculated by adding one to the mean weighed (by the relative abundance) trophic level of all food items consumed by a species (PAULY & CHRISTENSEN, 2000; TRITES, 2001). A relevant term is omnivory, an expression of the number of trophic levels on which a species feeds (CHRISTENSEN & PAULY, 1992). It can be quantified using the omnivory index, which is zero when a species feeds on items belonging to the same trophic level and increases with an increase in the variety of the prey's trophic levels (CHRISTENSEN & PAULY, 1992). The square root of the omnivory index is the standard error of the trophic level. Apart from the stomach contents, trophic levels can also be estimated from other experimental, empirical and modelling methods (STERGIOU & POLUNIN, 2000).

In marine ecosystems, trophic levels of consumers generally range between 2, for species feeding exclusively on plants or detritus, to 5.5 for carnivores, with the latter value characterising few specialised predators feeding on marine mammals (PAULY *et al.*, 2000c). In general, fish have trophic levels ranging between 2 and 4.7, marine mammals between 3.2 and 5.5, cephalopods and seabirds between 3.0 and 5.0, with most cephalopods around 3.7 and most seabirds >4.0, whereas other invertebrates are generally restricted to trophic levels below 3 (FROESE *et al.*, 2005; KARPOUZI, unpubl. data). Interested readers can find species-specific trophic levels of fishes in FishBase, the largest electronic encyclopaedia for fishes (FROESE & PAULY, 2003; FishBase online, www.fishbase.org).

ranged from 8 cm, for *Deltentosteus quadrimaculatus*, to 458 cm, for *Thunnus thynnus*.

The 111 datasets were derived from studies based on samples caught mainly with trawls (Figure VII.6a) and on a seasonal basis (Figure VII.6b). For 68 datasets, the stomach content's information was expressed using the gravimetric abundance (W) along with the numerical abundance (N) and/or frequency of occurrence (F) of prey in relation to the number of stomachs containing food (Figure VII.6c). For the remaining 43 datasets, diet composition was expressed as N and/or F or rank relative abundance (RA) of prey (Figure VII.6c), which used alone, are not adequate indices for expressing feeding in fishes (STERGIOU & KARPOUZI, 2002). The length range of the specimens studied was provided for 67 datasets (Figure VII.6d). The total number of stomachs analysed per dataset, ranged from 11 to 1 045, with half of the datasets being based on the analysis of less than 200 stomachs.

TROPHIC LEVEL ESTIMATES

Trophic levels were calculated using the quantitative routine of TrophLab (PAULY *et al.*, 2000c; a standalone Microsoft Access routine for estimating trophic levels, downloadable from www.fishbase.org).

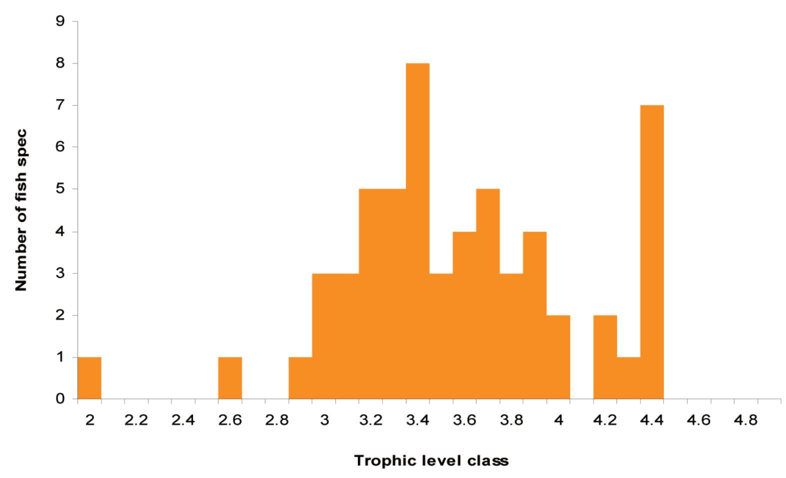


Figure VII.5:
Number of fish species per 0.1 trophic level class for the 58 Hellenic fish species shown in Table VII.3

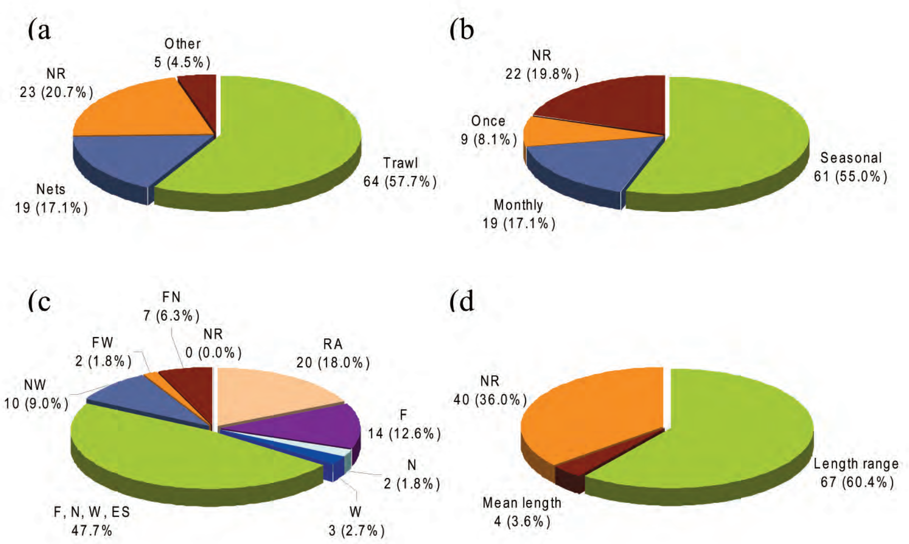


Figure VII.6:
(a) Sampling gear, (b) sampling frequency, (c) indices used for the expression of diet composition data (W = gravimetric contribution, N = numerical contribution, F = frequency of occurrence, RA = rank relative abundance) and (d) mean or range of body length of specimens reported, for the diet composition data compiled for 111 datasets of fishes from Hellenic waters. NR = Not Reported.

The estimated trophic levels ranged from 2.0 for *Siganus luridus* to 4.5 units for *Xiphias gladius, Dentex dentex, Epinephelus marginatus, Euthynnus alletteratus, Fistularia commersonii* and *Sarda sarda*, which can be considered as top predators (Table VII.3). The most intensively studied species were *Mullus barbatus, Merluccius merluccius, Lepidotrigla cavillone, Pagellus erythrinus* and *Mullus surmuletus*, represented by more than six datasets each, followed by 14 species each represented by two to four datasets (Table VII.4). The remaining 39 species were represented by 1 dataset only (Table VII.4).

The trophic levels estimated from the different datasets of the same species varied with dataset (Table VII.4). Thus, for the 19 species for which more than 1 dataset was available, the differences in the estimates ranged between 0.0, for *Xiphias gladius*, to 1.07, for *Serranus cabrilla*, with 8 species having a difference ranging between 0.20 and 0.40 units (Table VII.4). Such within-species differences in trophic levels might reflect the combined effect of the following factors: (a) area, because a species might feed on different prey in different areas; (b) year, because species' feeding habits might differ both within- and between-years; (c) length structure, because generally for carnivorous species trophic level increases with length; and (d) differential fishing pressure between years and/or areas, because fishing removes the largest individuals of a species, which generally have higher trophic levels.

The number of species per 0.1 trophic level classes is shown in Figure VII.7, from which five

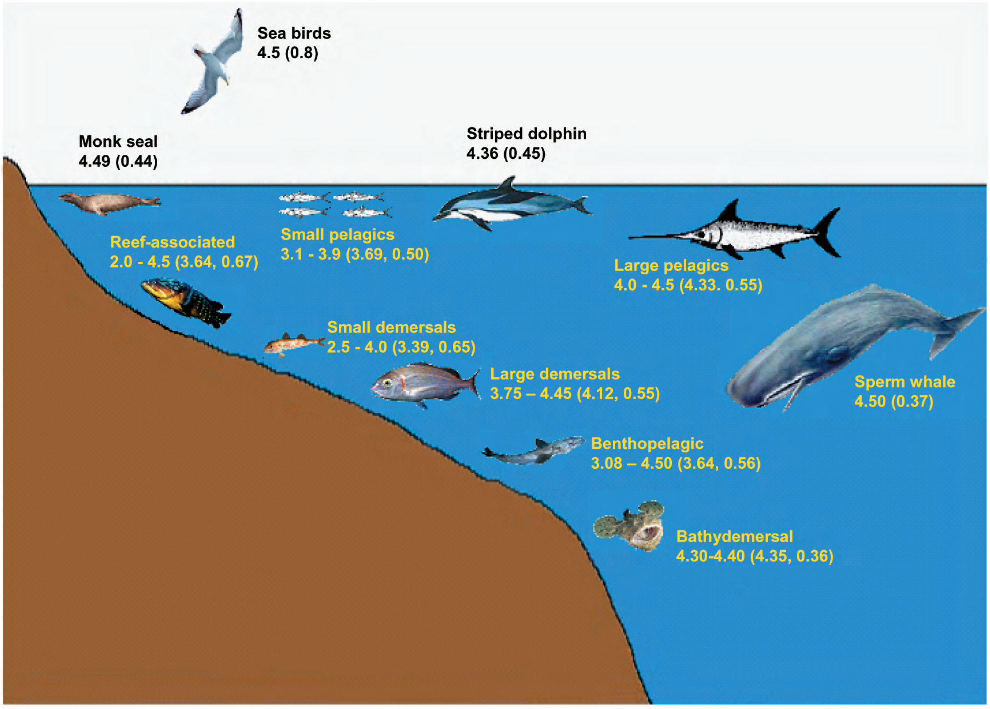


Figure VII.7: *Trophic levels (range and in parentheses, mean and standard error as estimated with TrophLab) of fishes by major habitat (i.e., pelagic, benthopelagic, reef-associated, demersal and bathydemersal: based on mean values from Table VII.4) together with the trophic levels of other top predators (i.e., marine mammals and seabirds) in the Hellenic Seas. The trophic levels of the monk seal, sperm whale, striped dolphin and sea birds were estimated from their published feeding habits in the Hellenic seas (references available from V. S. KARPOUZI. The main ecosystem components missing from this schematic outline are: phytoplankton and benthic flora (which by definition are at trophic level 1), zooplankton, cephalopods (which range from 3 to 4.5), large crustaceans and other benthic or pelagic invertebrates (see text for references).*

***The definitions of habitats**, listed below, are quoted directly from the glossary of FishBase (www.fishbase.org).*

*(a) **Demersal:** Sinking to or lying on the bottom; living on or near the bottom and feeding on benthic organisms.*

*(b) **Benthopelagic:** living and feeding near the bottom as well as in mid waters or near the surface and feeding on benthic as well as free swimming organisms. Also pertaining to forms which hover or swim just above the floor of the sea; the depth zone about 100 metres off the bottom at all depths below the edge of the continental shelf. (c) **Pelagic:** Living and feeding in the open sea; associated with the surface or middle depths of a body of water; free swimming in the seas, oceans or open waters; not in association with the bottom. Many pelagic fish feed on plankton. In FishBase, referring to surface or mid water from 0 to 200 m depth. (d) **Bathydemersal:** Living and feeding on the bottom below 200 m. and (e) **Reef-associated:** Living and feeding on or near coral reefs.*

Table VII.4: *Number of datasets (N) and trophic levels (minimum, maximum, their difference, mean) of fish in the Hellenic seas.*
H: habitat (RA: reef-associated, D: demersal, BP: benthopelagic, P: pelagic; for definition of habitats see Figure VII.7; common name and habitat of species are from www.fishbase.org). SE: Standard Error.

Species	Common name	Hapitat	Trophic level					
			%	Min	Max	Mean	SE	Difference
Siganus luridus	Dusky spinefoot	RA	1	2.00	-	2.00	0.00	-
Symphodus roissali	Five-spotted wrasse	D	1	2.66	-	2.66	0.36	-
Symphodus ocellatus	-	D	2	2.52	3.40	2.96	0.41	0.88
Spicara smaris	Picarel	D	1	3.10	-	3.10	0.35	-
Symphodus cinereus	Grey wrasse	D	1	3.10	-	3.10	0.39	-
Symphodus mediterraneus	Axillary wrasse	D	1	3.10	-	3.10	0.40	-
Cepola macrophthalma	Red bandfish	D	1	3.11	-	3.11	0.27	-
Sardina pilchardus	Sardine	P	3	3.10	3.20	3.16	0.36	0.10
Symphodus tinca	East Atlantic peacock wrasse	D	1	3.20	-	3.20	0.44	-
Mullus barbatus	Red mullet	D	11	2.79	3.50	3.25	0.45	0.71
Pagellus erythrinus	Common pandora	BP	6	3.08	3.43	3.26	0.48	0.35
Lepidotrigla cavillone	Large-scaled gurnard	D	6	3.10	3.43	3.26	0.45	0.33
Spicara maena	Blotched picarel	D	1	3.30	-	3.30	0.39	-
Deltentosteus quadrimaculatus	Four-spotted goby	D	1	3.30	-	3.30	0.44	-
Coris julis	Mediterranean rainbow wrasse	D	2	3.30	3.37	3.34	0.47	0.07
Trigla lyra	Piper gunard	D	2	3.33	3.35	3.34	0.49	0.02
Trachurus mediterraneus	Mediterranean horse mackerel	P	2	3.20	3.60	3.40	0.50	0.40
Diplodus annularis	Annular seabream	BP	1	3.40	-	3.40	0.46	-
Symphodus rostratus	-	D	1	3.40	-	3.40	0.51	-
Thalassoma pavo	Ornate wrasse	RA	1	3.42	-	3.42	0.49	-
Mullus surmuletus	Striped red mullet	D	6	3.16	3.58	3.44	0.52	0.42
Blennius ocellaris	Butterfly blenny	D	1	3.44	-	3.44	0.48	-
Pagellus bogaraveo	Blackspot seabream	BP	1	3.47	-	3.47	0.49	-
Gobius niger	Black goby	D	1	3.47	-	3.47	0.51	-
Lepidorhombus boscii	Fourspotted megrim	D	1	3.50	-	3.50	0.50	-
Lithognathus mormyrus	Striped seabream	BP	1	3.50	-	3.50	0.52	-
Hoplostethus mediterraneus	Mediterranean slimehead	BP	1	3.50	-	3.50	0.53	-
Pagellus acarne	Axillary seabream	BP	1	3.56	-	3.56	0.53	-
Chelidonichthys lastoviza	Streaked gurnard	D	3	3.54	3.65	3.59	0.54	0.11
Scorpaena porcus	Black scorpionfish	D	2	3.40	3.80	3.60	0.57	0.40
Serranus hepatus	Brown comber	D	3	3.50	3.73	3.65	0.57	0.23
Aspitrigla cuculus	East Atlantic red gurnard	D	1	3.67	-	3.67	0.57	-
Trisopterus minutus	Poor cod	BP	3	3.50	3.81	3.70	0.58	0.31
Serranus scriba	Painted comber	D	1	3.70	-	3.70	0.58	-
Pagrus pagrus	Common seabream	RA	4	3.63	3.90	3.74	0.59	0.27
Trachurus trachurus	Atlantic horse mackerel	P	2	3.60	3.90	3.75	0.56	0.30
Epinephelus caninus	Dogtooth grouper	D	1	3.80	-	3.80	0.60	-
Helicolenus dactylopterus	Blackbelly rosefish	D	1	3.80	-	3.80	0.62	-
Citharus linguatula	Atlantic spotted flounder	D	1	3.80	-	3.80	0.65	-
Serranus cabrilla	Comber	D	3	3.30	4.37	3.82	0.59	1.07
Raja radula	Rough ray	D	1	3.90	-	3.90	0.61	-
Scomber scombrus	Atlantic mackerel	P	1	3.90	-	3.90	0.66	-
Micromesistius poutassou	Blue whiting	BP	3	3.56	4.39	3.91	0.63	0.83
Uranoscopus scaber	Atlantic stargazer	D	1	4.00	-	4.00	0.61	-
Scorpaena scrofa	Largescaled scorpionfish	D	1	4.00	-	4.00	0.66	-
Thunnus thynnus	Northern bluefin tuna	P	1	4.00	-	4.00	0.66	-
Phycis phycis	Forkbeard	BP	1	4.09	-	4.09	0.72	-
Epinephelus aeneus	White grouper	D	1	4.10	-	4.10	0.56	-
Merluccius merluccius	Hake	D	7	3.75	4.45	4.21	0.70	0.70
Lophius piscatorius	Angler	BD	1	4.30	-	4.30	0.65	-
Lophius budegassa	Black-bellied angler	BD	1	4.40	-	4.40	0.64	-
Zeus faber	John dory	BP	1	4.43	-	4.43	0.79	-
Xiphias gladius	Swordfish	P	2	4.50	4.50	4.50	0.50	0.00
Dentex dentex	Common dentex	BP	1	4.50	-	4.50	0.73	-
Epinephelus marginatus	Dusky grouper	RA	1	4.50	-	4.50	0.73	-
Euthynnus alletteratus	Little tunny	P	1	4.50	-	4.50	0.80	-
Fistularia commersonii	Bluespotted cornetfish	RA	1	4.50	-	4.50	0.80	-
Sarda sarda	Bonito	P	1	4.50	-	4.50	0.80	-

general modes can be identified. These modes generally correspond to the following functional trophic groups identified by STERGIOU & KARPOUZI (2002) for the Mediterranean Sea: (a) pure herbivores (trophic level=2.0-2.1); (b) omnivores with a preference for vegetable material (2.1 < trophic level < 2.9), but also feeding on other prey; (c) omnivores with a preference for animals (2.9 < trophic level < 3.7), the dominant group; and (d) carnivores (3.7 < trophic level < 4.5). The last group was further subdivided into two subgroups, one exhibiting a preference for decapods and fish (3.7 < trophic level < 4.0) and another one exhibiting a preference for fish and cephalopods (4.0 < trophic level < 4.6).

The distribution of the trophic levels of fishes by major habitat (i.e., pelagic, benthopelagic, demersal, reef-associated, bathydemersal) together with those of other top predators of the Hellenic marine ecosystems (i.e., marine mammals and seabirds) are shown in Figure VII.7.

RELATIONSHIP BETWEEN TROPHIC LEVEL AND BODY SIZE

The trophic levels of the fish species in the Hellenic Seas were plotted against their maximum reported body size (based on a log-log plot) using the same plot for all Mediterranean datasets as a background (Figure VII.8). The Mediterranean background plot was based on the datasets reviewed by STERGIOU & KARPOUZI (2002) as well as on 123 additional datasets for the Mediterranean Sea (references for the diet composition and trophic level estimates of these 123 datasets are available from V. S. KARPOUZI).

From Figure VII.8 it is evident that a positive relationship exists between trophic level (and its mean value per species) and maximum body size (i.e., trophic level increases with an increase in species' size), with the latter accounting for 35% of the variance in trophic level. This percentage increased to 30-43% when the datasets of the pure herbivores *Siganus luridus, S. rivulatus* and *Sarpa salpa* were not taken into account in the analysis (Figure VII.8). Such a relationship is very useful for estimating trophic levels for species for which no information is available on their feeding habits.

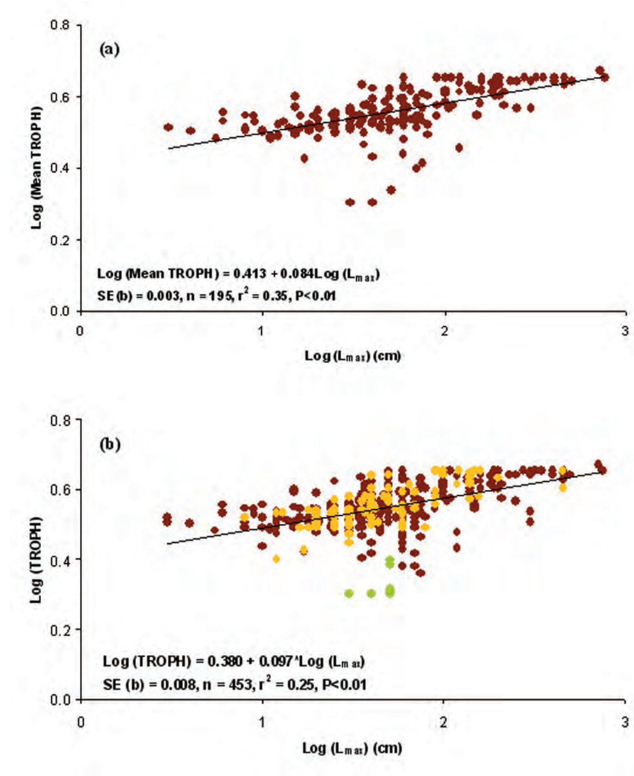


Figure VII.8:
Relationship between maximum reported body length (L_{max}) (extracted from 'FishBase online'; www.fishbase.org) and: (a) trophic level (TROPH) of the 330 datasets in STERGIOU & KARPOUZI (2002) and 123 additional, newly acquired datasets (references available from V.S. KARPOUZI); (b) mean TROPH per species. Red circles correspond to datasets referring to fish stocks elsewhere in the Mediterranean but in Hellenic waters (yellow circles). When the lower outliers (green circles, corresponding to the datasets of the pure herbivores Siganus luridus, S. rivulatus and Sarpa salpa) were not included in the analysis, the regression equations were for (a) Log(TROPH) = 0.389 + 0.095Log(Lmax) [SE(b) = 0.007, r2 = 0.30, n = 442, P<0.01] and for (b) Log(Mean TROPH) = 0.420 + 0.082Log(Lmax) [SE(b) = 0.002, r2 = 0.43, n = 192, P<0.01].

VII.3. MARINE AQUACULTURE SECTOR OF HELLAS 1985-2002

The extended length and morphology of the Hellenic coastline, forming a large number of sheltered areas and gulfs, as well as the existence of numerous islands and the mild climate, provide the ideal conditions for all forms of mariculture. The majority of the cultivating units use intensive rearing methods in floating cages (Figure VII.9) or in concrete raceways. However, semi-intensive techniques in earthen ponds with supplemented feeding as well as extensive forms in lagoons and land-based ponds can be found. In Hellas, today, all forms of mariculture are practised and the main species produced are summarised in Table VII.5.

Marine **finfish culture** is practised mainly in

Table VII.5: *List of main species (common and scientific names) currently produced in Hellas and respective methods of cultivation.*

SPECIES	EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
Sea breams *(Sparus aurata)*	+	+	+
Sea bass *(Dicentrarchus labrax)*	+	+	+
Mullets	+	+	Just starting
Other sea breams	+	+	Just starting
Mediterranean mussel *(Mytilus galloprovincialis)*			+
European flat oyster *(Ostrea edulis)*			+
'Kuruma' prawn *(Marsupenaeus japonicus)*	+	+	

Source: *NATURA 2000.*

Figure VII.9: *Finfish culture - North Evvoikos Gulf.*

floating cages in inshore areas or close to shore areas with limited exposure to the open sea or weather (Figure VII.10). The Hellenic finfish production is characterised by the dominance of two main species. European sea bass *(Dicentrarchus labrax)* and Gilthead sea bream *(Sparus aurata)* which represent 48% and 50% of total production and by about 10 other species, which all represent only 2% of the total production. The origin of fry depends on the species and for sea bass and sea bream, whose production cycle is totally controlled for all the stages of their life cycle, the majority of fry is produced in hatcheries. For the other species, whose biological cycle is not yet totally controlled, fry is obtained from wild fishing followed by adaptation to captivity. Only recently some hatcheries started to produce new species fry such as red porgry, red pandora, striped seabream and grey mullet.

The shellfish aquaculture industry shows low species diversity and almost entirely depends on the farming of the Mediterranean mussel *Mytilus galloprovincialis* (Bivalvia, Mytilidae). Two other species, the European flat oyster and 'kuruma' prawn are cultivated, however, with very low production.

With regard to **mussel culture**, there are two systems employed; the traditional rack-hanging system installed in relatively shallow areas (-10 m) and the more modern 'buoyed long-line' deployed offshore (Figure VII.11). Both use inland facilities. Today, both systems are in use. However, there is a trend towards the long-line system which is also supported by financial aid from the EU and the Hellenic Ministry of Agricultural Development and Food (45% on the final investment). Mussels in both methods are stocked in special mesh netting, called 'socks', hanging from a wood or galvanized tube in the rack-hanging system or from the main horizontal rope in the long-line system. Mussel farming is based on natural settlement. Spat is commonly collected from vertical nets and ropes used as 'collectors' hanging in the water column during the two main reproductive peaks of the year (autumn, spring).

Oyster culture depends on the farming of *Ostrea edulis* (Bivalvia, Ostreidae). The species is reared in only one unit located in Argos (Peloponnisos,

Figure VII.10:
Finfish culture in Larymna area.

Photo: *V.A. CATSIKI.*

southeastern Hellas) using the long-line cultivation system. Production is directed only to the domestic market.

With regard to **prawn culture**, the target species for more than a decade in Hellas has been the 'kuruma' prawn *Marsupenaeus japonicus* (Crustacea, Penaeidae) (Figure VII.12). The species has been successfully introduced, acclimatised and reared both in the Ionian (Amvrakikos Gulf) and the Aegean seas. The culture systems applied were mainly extensive and semi-intensive in earthen ponds. Since 1994 there is only one prawn farm cultivating the species with the semi-intensive method, although not systematically and is located in Alexandroupoli (Thraki, northeastern Hellas). The farm consists of indoor pregrowing cement tanks and outdoor growing earthen ponds. In 1992, the subtropical species *Litopenaeus vanname* was cultivated unsuccessfully in the same prawn farm.

Photo: *K. KEVREKIDIS.*

Figure VII.11:
Mussel culture.

Photo: *K. KEVREKIDIS.*

Figure VII.12:
Marsupenaeus japonicus.

PRODUCTION UNITS IN HELLAS

The number of marine fish and molluscs farms and hatcheries has increased rapidly over the period 1985-2002 and is summarised in Figure VII.13 and in more detail for the year 2002 in Figure VII.14. The spatial distribution of marine fish and mollusc farms in Hellas in 2002 is illustrated in Figure VII.15.

Mussel farming is one of the most dynamic sectors of Hellenic aquaculture focusing on the rearing of *Mytilus galloprovincialis*. 574 mussel farms exist today with the majority of those deployed in gulfs and bays of northern Hellas, with 88% of farms being installed in the Thermaikos Gulf. In such a marine area, where high concentration of nutrients often leads to eutrophication especially in the northwestern part of the gulf, where mussel farming is expanded, significant growth of mussels can be exhibited in a relatively small period of time. It is estimated that in a period of 7-8 months from spat collection, mussels reach commercial size (5-6 cm in shell length) and can be harvested.

According to EU Directive 91/492 and the Hellenic legislation, a water quality assurance

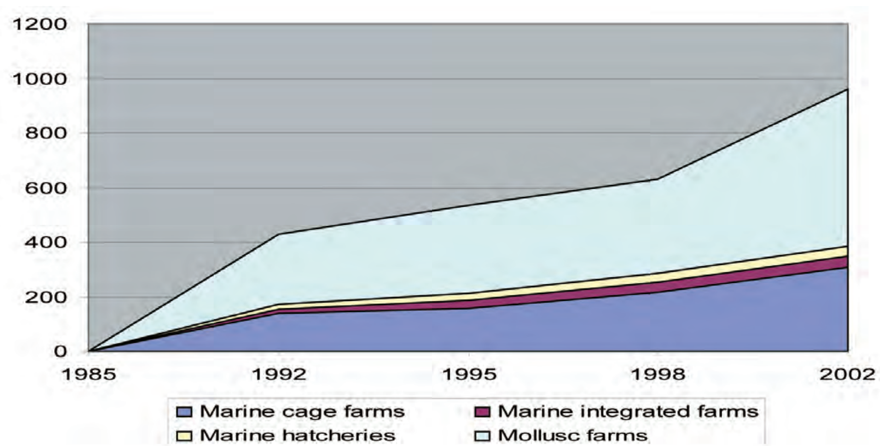


Figure VII.13: *Development of the Aquaculture sector in Hellas (1985-2002).*

Source: *HCMR based on data from Agricultural Bank of Hellas; annual reports.*

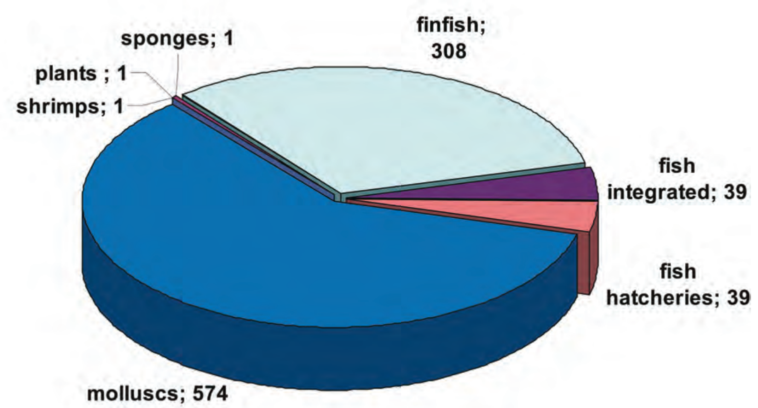
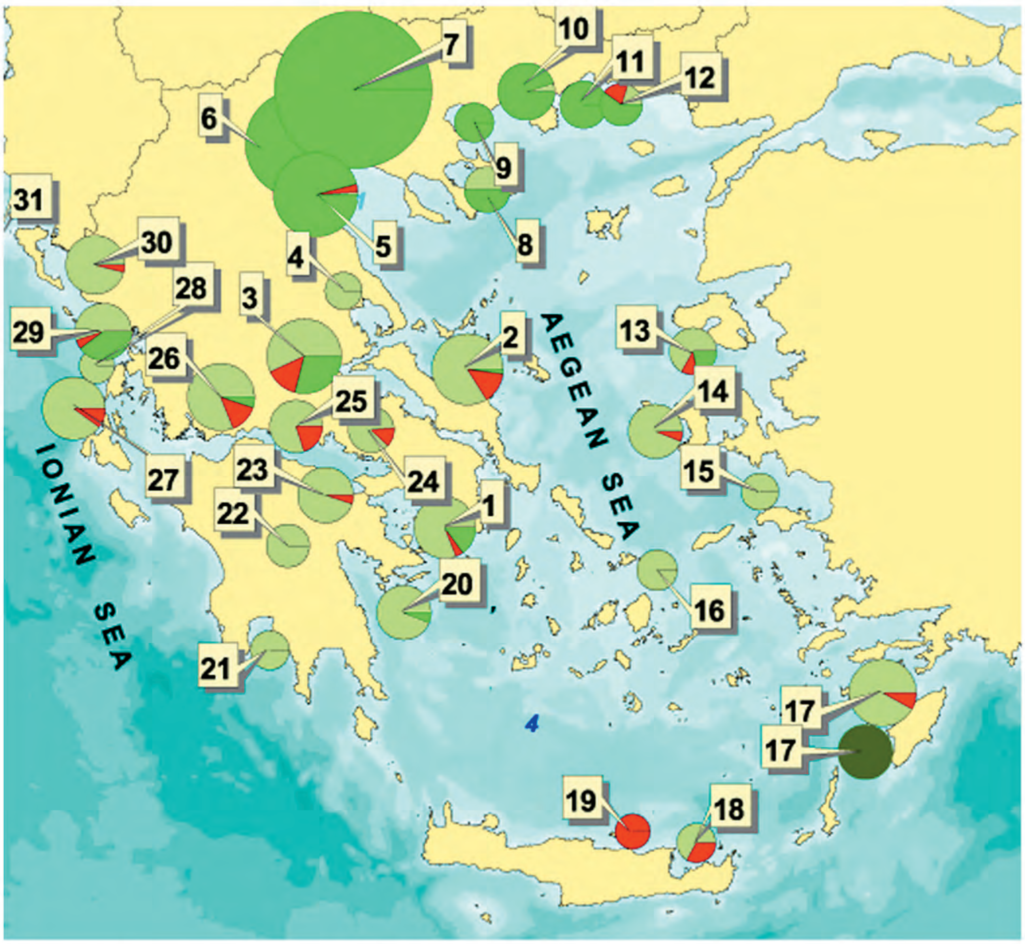


Figure VII.14: *Aquaculture production in Hellas in the year 2002.*

Source: *HCMR based on data from Ministry of Agriculture, Directorate Fisheries, Section of Mariculture.*

programme has been implemented for the shellfish growing sites including sampling of water and of shellfish. The main goal of the assurance programme is to ensure the quality of the mussel product being harvested for both the domestic and export market. Furthermore, the directive EU 91/493 determines the regulations relating to the sanitary practices for the export and import of



Number of aquaculture units

Fish | Fish Hatcheries | Shellfish | Sponges

Total number of units per prefecture

1. Attiki: 27 units
2. Evvoia: 3 "
3. Ftihotida:49 "
4. Magnisia: 2 "
5. Pieria: 69 "
6. Imatheia:130 "
7. Thessaloniki: 308 "
8. Chalkidiki: 4 "
9. Serres: 3 "
10. Kavala: 20 "
11. Xanthi: 9 "
12. Rodopi: 5 "
13. Lesvos: 9 "
14. Chios: 17 "
15. Samos: 2 "
16. Kyklades:4 "
17. Dodekanisos: 38 "
18. Lasithio: 3 "
19. Irakleio: 1 "
20. Argolida: 17
21. Messinia 3 "
22. Arkadia: 6 "
23. Korinthia: 19 "
24. Voiotia: 8 "
25. Fokida: 15 "
26. Aitoloakarnania: 36 "
27. Kefallinia: 29 "
28. Lefkada: 1 "
29. Preveza: 20 "
30. Thesprotia: 23 "
31. Kerkyra: 1 "

Source: *Ministry of Agriculture, Directorate Fisheries, Section of Mariculture.*

Figure VII.15: *Marine fish, prawn and mollusc farms in Hellas (number per administrative region); 2002 data.*

mussels including handling, processing, packaging, shipping conditions, labelling requirements, storage, repackaging and controlled purification of shell stock. Up to now 13 processing and two purification plants are operating in Hellas.

An important statistical parameter for the evaluation of the potential of aquaculture is the volume of the exploited waters. The exploited volumes for intensive mariculture have increased over 500% during the period 1990-1995. It was expected to stabilise at about 4 500 000 m^3 during the next decade due to the unavailability of suitable sites but an increasing trend still exists. The trends in intensive farms' capacity are summarised in Table VII.6.

AQUACULTURE PRODUCTION IN HELLAS

Commercial fisheries product consumption in the Hellenic market increased from 115 000 tonnes in 1974 to 266 214 tonnes in 2002; from 40 000–50 000 tonnes are imported and the rest come from local fisheries and aquaculture.

Aquaculture production of European sea bass, gilthead, and sea bream since 1985 is summarised in Table VII.7. Another source of information is the FAO Fishstat database up to 2001 (Table VII.8).

The production of sea bass and sea bream in Hellas has increased dramatically over the period 1985-2002. Hellas today is by far the leading

Table VII.6: *Trends in intensive fish farm capacity in Hellas.*

TYPE	1990	1991	1992	1993	1994	1995	1996	1997	1998	2002
Marine fish CAGES (in 1 000 m^3)	470	823	1 230	1 450	2 200	2 714	3 460	3 600	4 150	5 800
Marine fish PONDS (in 1 000 m^3)					60	60	60	40	20	20
Molluscs (in 1 000 m^2)	470	823	1 230	1 450	2 260	2 774	3 520	3 640	4 170	6 400

Source: *Agriculture Bank of Hellas.*

Table VII.7 *Sea bass and sea bream aquaculture production in Hellas (in tonnes) since the first production year.*

SPECIES	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	2002
Sea bream	200	500	850	1 277	2 402	4 800	6 670	9 167.0	12 765	13 680	19 550	37 006
Sea bass			750	1 182	2 443	4 700	6 830	8 386.0	11 235	11 820	13 540	25 451

Source: *Agriculture Bank of Hellas.*

Table VII.8: *Aquaculture production of the main species cultivated in Hellas (in tonnes).*

	1995	1996	1997	1998	1999	2000	2001
European sea bass	9 511	11 599	15 145	18 429	24 345	26 519	25 185
Gilthead sea bream	9 331	13 715	17 935	21 837	32 644	38 347	40 477
Common pandora						2	7
European eel	42	22	21	28	40		1
Red porgy							
White sea bream	1	122	1	37	107	84	68
Others	39	305	595	1 286	2 041	1 842	1 476
TOTAL FISH	**18 924**	**25 763**	**33 697**	**41 617**	**59 177**	**66 794**	**67 214**

Source: *FAO Fishstat .*

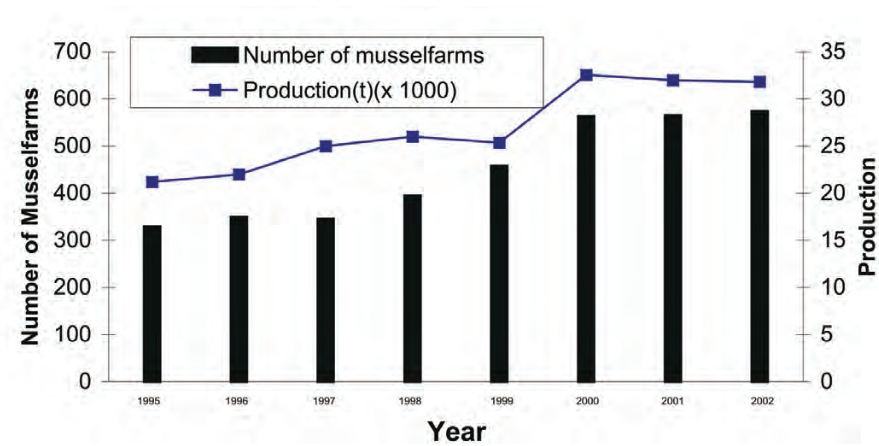
producer in Europe of marine euryhaline finfish from aquaculture (Box 2).

Mussel production has increased by 50% over the period 1995-2002. However, it has been stable for three consecutive years (2000-2002) whereas it is expected to exceed 33 000 tonnes before 2004. More than 90% of the national production of mussels is produced in the Thermaikos Gulf. Annual production of mussels and the increase in number of mussel farms in Hellas over the period 1995-2002 is illustrated in Figure VII.16.

The annual production of the prawn *M. japonicus* and the respective value for the period 1995-2002 are summarised in Table VII.9. Production is mainly exported.

Box 2: *Accuracy of data on Fishery / Aquaculture production*

An important problem concerning the dissemination of administrative data of the sector is that in 1998 the offices of annual reports of the Agriculture Bank of Hellas stopped the production of annual sectoral reports on aquaculture and fisheries. Thereafter, the accuracy of information decreased significantly. The only available information is from FAO Fishstat database regarding production statistics and the Federation of European Aquaculture Producers (FEAP) at www.feap.org. Though, in both cases, the wealth of information included in the annual reports of the Agriculture Bank of Hellas is not offered. Fortunately, the Directorate of Aquaculture and Inland Waters of the Hellenic Ministry of Agriculture initiated an annual publication regarding the annual aquaculture sector statistics from 2002. The data in this annual report have also been used in this paper where applicable.



Source: *Ministry of Agricultural Development and Food.*

Figure VII.16: *Annual production of mussels and number of mussel farms in Hellas over the period 1995-2002.*

Table VII.9: *Annual production of Marsupenaeus japonicus and respective value for the period 1995-2002.*

YEAR	1995	1996	1997	1998	1999	2000	2001	2002
Production (MT)	3	0	6	2	0	0	0	4
Value (€)	29 350		63 400	21 130				52 000

Source: *Ministry of Agricultural Development and Food.*

FRY PRODUCTION OF MARINE FINFISH IN HELLAS AND THE MEDITERRANEAN

An important issue in aquaculture is the availability of good quality and sufficient quantity of fry. Before 1988, Hellenic production was based upon the import of fry from other Mediterranean countries, mainly France and Italy. However, the production of sea bass and sea bream in Hellas has risen steeply over the period 1989-2002 and the overall production increased approximately by a factor of 35 during that period (Table VII.10). In 2002, 39 hatcheries operated in Hellas and produced a total amount of about 270 million fry of sea bass and sea bream representing more than 50 % of the total Mediterranean production.

The fry production method has not changed significantly since 1985 when the first know-how was transferred from France, along with the fry required for the first small cage fish farms. However, new techniques and new tools are used in order to reduce the production costs and increase the productivity of the existing hatcheries in terms of fry production.

The great rise of fry production, from zero individuals in 1984 (all fry was imported) to almost 269 506 513 fry in 2002 (less than 10 % of the fry is imported) is owed to:

- Structural support measures from the EU and the Hellenic Government (EU/4028/86 and 3699/93/EU), which provided funds to cover almost 55 % of the installation costs of fish farms. This way, more hatcheries were built and the facilities of the existing hatcheries were expanded to increase production;
- The decrease of overall mortality rates due to high availability of eggs from good quality broodstock and the use of live food with high nutritious value due to the use of enrichments;
- Research and development projects focusing on various aspects of aquaculture production:
  - Broodstock feeding for better quality eggs (new fish feeds).
  - Better handling procedures for eggs, larvae and juveniles.
  - Description of the optimum environmental conditions for rearing (temperature, salinity, dissolved oxygen, effects of light intensity, etc.) and abiotic factors (rearing densities).
  - Use of new technology in rearing (liquid oxygen, CO_2 for phytoplankton, better fish feed, size and shape of tanks, etc.).
  - Research on pathology and production of vaccines or antibiotics suitable for these species. Until almost 1994, livestock drugs (for chicken, etc.) and vitamin mixes were used to treat diseases. Today, drugs and vitamins targeted at these Mediterranean species are produced.

Regarding mussel and oyster culture, the exploitation of naturally occurring spats is the main method of initialisation of the production cycle. In a few cases, spats of the Mediterranean mussel were transferred to other areas within Hellas to aid the production cycle of farms (for example, on several occasions, mussel spats were transferred from the Thermaikos Gulf to Kalloni Bay in Lesvos Island).

There is no prawn hatchery operating in Hellas and post-larvae of *M. japonicus* for the one farm cultivating the species are currently imported, mainly from Spain. However, since the late 1970s the autochthonous species *Melicertus kerathurus* has been successfully reproduced in the laboratory whereas on-growing cultivation of the prawn has not yet been accomplished.

FUTURE OF AQUACULTURE

Except for the sea bass and sea bream species cultivated today, research has also focused on the reproduction and on-growing technology of other

Table VII.10: *Fry production (in thousands) and prices (€) in Hellas from commercial hatcheries.*

SPECIES	1992	1995	1998	2002
Sparus aurata	12 100	51 575	94 903	159 683
Dicentrarchus labrax	22 550	52 192	83 308	109 824
TOTAL Fry production	34 650	103 767	178 211	269 507
Price of *Sparus aurata*	0.34 €	0.25 €	0.24 €	0.26 €
Price of *Dicentrarchus labrax*	0.34 €	0.28 €	0.25 €	0.24 €

species in an attempt to increase the number of final products from aquaculture. These species in Hellas today are the mullets (mainly *Mugil cephalus*), the porgies (mainly *Pagrus pagrus* and *Pagrus major*) and sea breams (mainly *Puntazzo puntazzo*). In addition, attempts have been made to cultivate the red Pandora (*Pagellus erythrinus*), the snapper (*Dentex dentex*) and groupers (*Epinephelus aeneus, Epinephelus costae* and *Epinephelus marginatus*). The experience gained so far is summarised in Table VII.11. The first attempts for mass production of fry of other marine species started in 1995 and the first results were obtained in 1996 (Table VII.12).

As a need for the introduction into the industry of new shellfish species with high commercial value, research has focused on experimental rearing of scallop *Flexopecten glaber,* crayfish *Astacus astacus* and octopus *Octopus vulgaris*.

EXPORTS

A major part of the final production is exported annually to other European countries mainly through Italian wholesalers, while a small percentage of about 5-10% is directly exported to Spain, England and Germany. This percentage of the production exported is almost stable and ranges between 60-70%. The species that dominates exports is sea bass, while sea bream is considered a more popular product for the Hellenic domestic market.

Concerning mussels, exports represent almost one-third of the total national production and refer mainly to live and less to processed mussels. Exports increased by more than 250% over the period 1995-1999. In 1999 a peak of exports was recorded (17 800 tonnes); however, since then and up to 2002 exports declined by almost 35%.

Table VII.11: *Experience on the biology of marine finfish.*

SPECIES	REPRODUCTION	LARVAL REARING	ON-GROWING
Dicentrarchus labrax	known	known	known
Sparus aurata	known	known	known
Pagrus major	known	known	known
Pagrus pagrus	not known	not known	known
Dentex dentex	known	with problems	under research
Diplodus sargus & Diplodus vulgaris	not known	with problems	with problems
Puntazzo puntazzo	under research	under research	known
Seriola dumerilii	not known	not known	under research
Pagellus acarne & Pagellus bogavareo	not known	not known	known

TableVII.12: *Production of new species in Hellenic aquaculture (in thousand fry).*

SPECIES	1995	1998	2002
Mugil cephalus	425	100	
Pagrus spp.	88	1 740	
Puntazzo puntazzo	211	3 694	
Diplodus sargus sargus		190	
Pagellus erythrinus		50	
TOTAL	**724**	**5 774**	**17 548**[1]

[1] The Agriculture Bank of Hellas did not provide a breakdown of this amount but it should reflect the increase of production of *Puntazzo puntazzo* and porgries (*Pagrus* spp.).

Almost all the exported production is directed annually to European countries. For 2002, Italy was the leading country importing more than 80% of live product, followed by France, Spain, Ireland, Germany, etc., whereas the processed product is mainly exported to Germany, France, Belgium, etc. For the same year the value of exported live and processed product exceeded EUR 6.7 million.

The annual exported amounts of sea bass and sea bream whole fresh fish are summarised in Table VII.13.

The main problem that affects prices and the overall income of the Hellenic aquaculture sector is the overproduction of sea bass and sea bream in the Mediterranean region and the competition from producers from various countries. Two issues must be addressed here:

The Hellenic producers have organised export networks towards the EU countries through fish wholesalers in Italy. This exclusive type of export network is vulnerable when other producers from other countries with lower costs and lower prices use the same export route.

The second issue is the diversification of products. Today the main products are sea bass and gilthead sea bream, whole fish fresh on ice. A lot of efforts are made towards this direction with research and development activities for the introduction of new species in aquaculture.

EMPLOYMENT IN AQUACULTURE

In 2002 there were 4 745 personnel directly occupied in the Hellenic aquaculture industry and 1759 as part-time. More than 7 000 people were estimated to work in secondary industries and related activities. The secondary support industry for the Hellenic aquaculture is fully developed today and the needs of production are covered. In addition, numerous representatives exist today for imports of equipment and technology from EU countries, USA and elsewhere. The main characteristic of the Hellenic support industry is that one can find everything needed to set up and operate a fish farm or hatchery using Hellenic or international (imported) technology. The quality and prices differ significantly and therefore, depending on the feasibility of any plan, the appropriate equipment and technology can be found in Hellas.

Table VII.13: *Exports of final product (in tonnes) and mean prices (euros per kg) from Hellenic aquaculture sector.*

SPECIES	1992	1995	1998
Sparus aurata	810	4 422	10 360
Price/kg in €	6.90	4.70	6.45
Dicentrarchus labrax	2 107	6 705	10 820
Price/kg. in €	7.35	5.28	6.75
TOTAL export in tonnes	**2 917**	**11 127**	**21 180**

VII. GAPS IN KNOWLEDGE - FUTURE PERSPECTIVES

- According to the Common Fishery Policy of the EU the main instrument for fisheries' management is the management of fishing effort. The implementation of this policy led to the decommissioning of fishing vessels by each country member. The decommissioning process, however, should be conducted taking into consideration the following issues: (a) the decommissioning should be conducted in a geographically uniform manner to avoid reducing the local fleets considerably, (b) the reduction of the fleets should not affect the supply chains of the markets especially by increasing the cost of the final product or reducing supply, and (c) the balance between fleets operating in transboundary waters should be maintained. In addition, the fishing effort should be controlled considering the operational effort (active fleet) and not the total effort as it is today, since a good percentage of vessels is not operational throughout the year. Another measure that should be considered is the feasibility of the uniform distribution of the fishing effort in all available fishing grounds.
- There is the need to set landing minimum sizes in all commercially important species. The biology of the species should be considered when new laws and regulations are produced and enforced. fisheries' management needs to have a spatial and temporal dimension considering the biological cycles of the species and the geographic extent of the main physiological events (for example, the nursery grounds, etc.).
- There are limitations (mainly infrastructure and personnel) in law enforcement by the Hellenic Coast Guard. Moreover, the existing legislation needs to be consolidated and updated.
- The Hellenic fishing industry must use selective fishing gears based on the long research on the subject and mainly on the trawled gears (trawlers, shore seines, etc.).
- Research needs to be conducted on the application of new management systems for the Mediterranean such as property rights, TACs and QUOTAs even in the small and artisanal fisheries.
- The Fisheries Observers Corp. needs to be organised within the Ministry of Rural Development and Food.
- Hellenic aquaculture production has been based on two species – *sea bass and sea bream*, and one type of market product – *whole fish, fresh on ice*. The market needs to be diversified in order to keep the market price as high as possible. The attempts to use more species in aquaculture have not been supported by research on the reproduction of new species, feeding and pathology.
- The intensive exploitation of the Hellenic coastal zone for a large variety of economic activities (tourism, urban development, industry, agriculture, aquaculture and fisheries) creates significant conflicts, which hinder the development of coastal aquaculture. It is imperative that ICZM plans will be set in order to spatially organise all these activities and reduce conflicts.
- The Hellenic structural plan EPAL 2000-2006 was not exploited for aquaculture development as was expected. Better management of the farms is required.
- There is a lack of trained personnel capable to work in aquaculture farms and especially with new species other than sea bass and sea bream.
- There are many commercially exploited fish species such as *Scomber japonicus, Sardinella aurita, Sprattus sprattus, Merlangius merlangus, Auxis spp., Pomatomus saltatrix, Mustelus spp., Psetta maxima, Sphyraena spp. Belone belone, Dentex macrophthalmus, Squalus acanthias, Caranx spp., Squatina squatina, Platichthys flesus, Katsuwonus pelamis, Thunnus obesus* and *Pleuronectes*

platessa as well as non-commercial ones of high abundance in certain habitats such as *Argentina sphyraena, Capros aper, Gobiidae, Myctophidae, Macrouridae, Raja* spp., etc. for which no information is currently available on their diet in Hellenic waters. The study of the feeding habits of the above-mentioned species and of other important components of the marine ecosystems such as large crustaceans, cephalopods, marine mammals, turtles and seabirds together with estimates of their trophic levels is of primary importance for quantifying trophic interactions and energy flow as well as for the identification of the effects of fishing on the Hellenic marine ecosystems.

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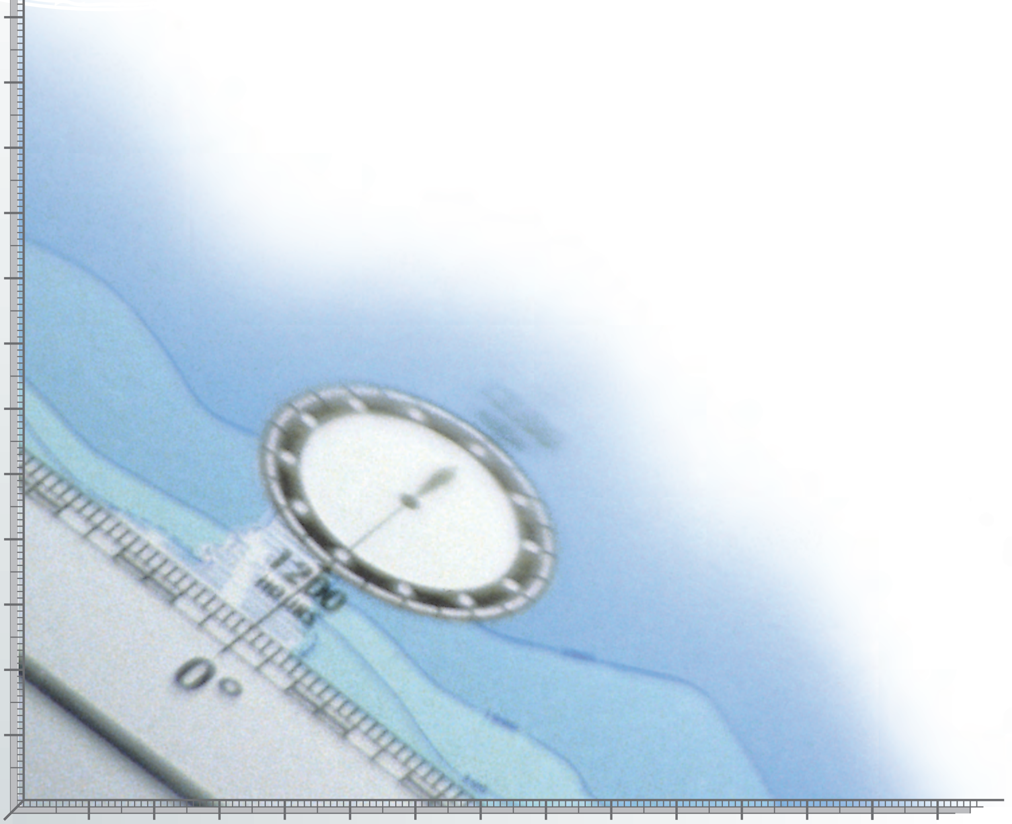
CHAPTER VIII
HUMAN ACTIVITIES



VIII.1. ANTHROPOGENIC ACTIVITIES ALONG THE HELLENIC COASTS

Hellas is characterised by a high coastal concentration of the population. One third of the total population is living on a relatively narrow land zone along the Hellenic coastal area. The anthropogenic activities influencing the natural environment on the Hellenic coasts can be grouped as follows: urbanisation, industry, agriculture, aquaculture, tourism, recreational areas and waste disposal. An effort to outline these activities is shown in Figure VIII.1, where we can identify two main activities extending along the Hellenic coastline: (1) tourism and (2) the recreational areas, namely, 'second homes'.

These pressures on the coastlines create various conflicts between different user groups of the coastal environment. There is a need to manage the coast and to maintain or improve the state of the coastline used by man. It includes the composing and the policing of any necessary regulations and decisions for the design and location of any structures needed to facilitate the use of the coastline.

When trying to introduce some management principles in the different discussion and decision levels some important questions arise, which need definition and analysis.

- In what degree do the activities on the coast facilitate the general development of Hellas?
- What sort of development does Hellas need nowadays?
- Can development in Hellas be based on sustainability?
- How can the socio-economic structure of Hellas, as part of the European community, respond to the international competitiveness?

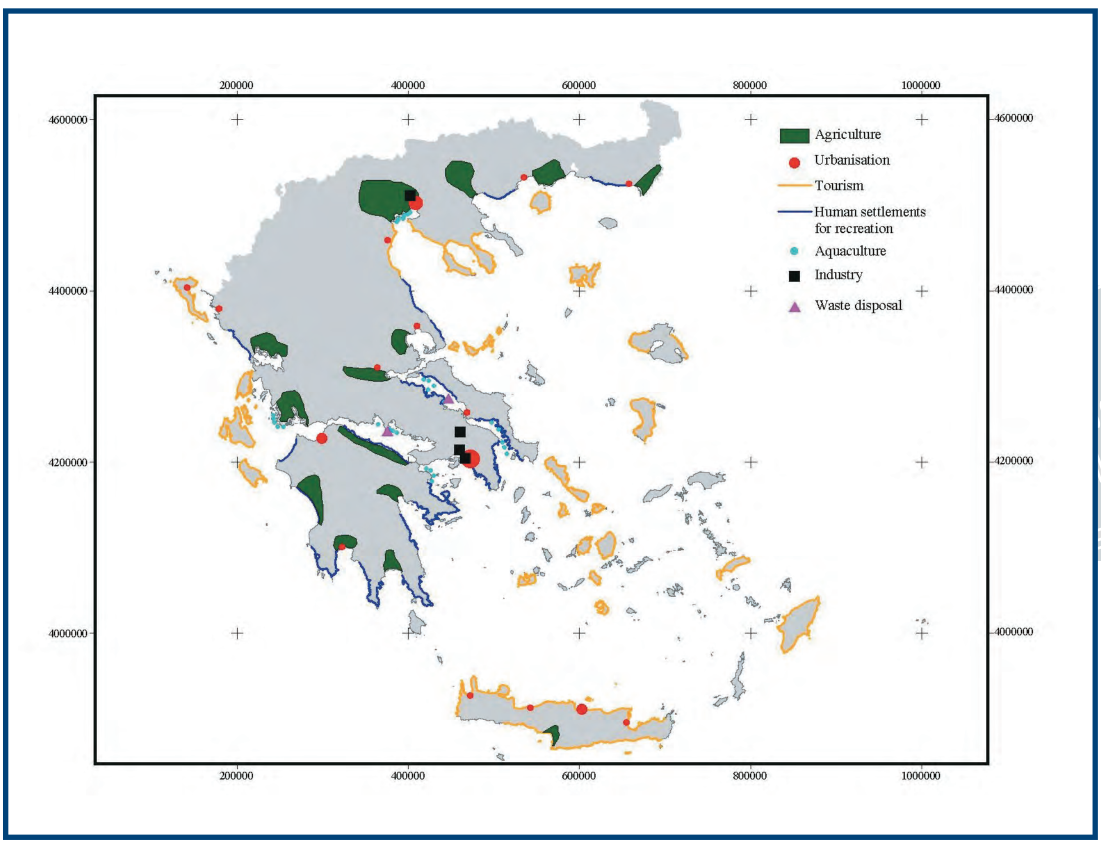


Figure VIII.1: Anthropogenic activities along the Hellenic coastlines.

- How can sustainable development be defined and how can there be compatible sustainable development and competitiveness?

It is out of the scope of this contribution to deal with these questions. We shall give some examples to show how the anthropogenic activities on the coast affect the functioning and the configuration of the coast, influencing the value of the coastal system and related also to the above-formulated questions.

Our vision starts from the point that the Hellenic coastline is regarded as public areas, although some of them and for different reasons, are privately owned.

Urbanisation

Most of the big cities in Hellas are located on the coast. The total urbanised coastal area is estimated around 1.3% of the total land with indication of a further increase in the future. Half of the Hellenic population lives in two coastal population centres of Hellas: Athens and Thessaloniki. The coast in these two areas is intensively used as commercial and passenger, fishing and yachting harbours; for houses, shops, hotels, waterfronts, refreshment kiosks and beaches used for access to the sea for swimming. (Figure VIII.2) In Athens the largest rivers in the area, the Kifissos and Ilissos, flow only during the winter period. It is striking that so many uses, some of them controversial, near big cities like Athens with a population of more than 4 000 000 people can be identified. Athens is also one of the few large cities of the world whose beaches can be used for swimming.

Industry

Industrial activities are closely related to urbanisation. More than 80% of the industrial activities in Hellas are located on the coast. Significant quantities of heavy 'metals' are introduced to the marine environment by direct discharges of industrial and domestic wastes. These inputs may have an impact on the marine ecosystem or even be locally dangerous to human health via the consumption of seafood. For more details on coastal areas prone to such effects and levels of metal contamination see Chapter IV.3.

To the west of Athens lies the most heavily industrialised (and urbanised) shoreline of Hellas

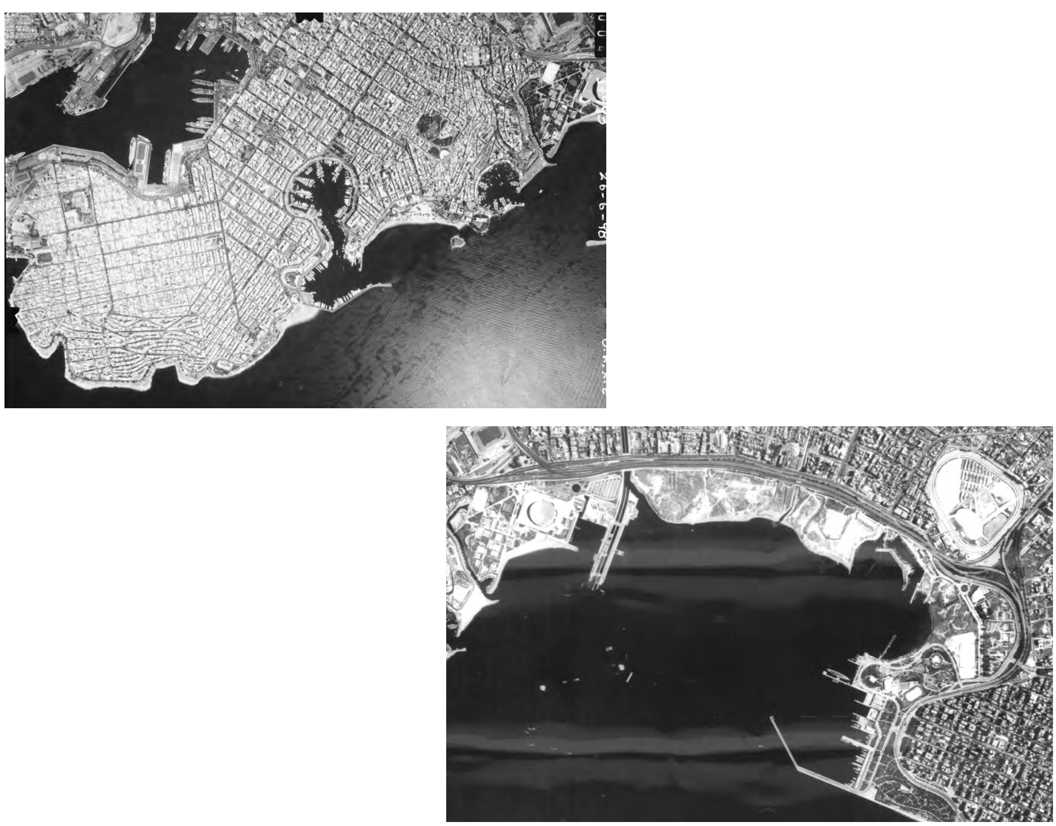


Figure VIII.2: *Aerial photos showing the urbanisation and the anthropogenic uses along the coastline of the city of Peiraia (port of Peiraias, small yachting marinas, regulation of the Kifissos river outflow, sport constructions and changes of the coastline through deposition of earth material).*

(Elefsis basin, Figure VIII.3). During the last 25 years a large portion of the industrial activities have been transferred to a relatively new industrial area in the northern part of Attiki. Similar activities can be identified in the urbanised coastal areas of Thessaloniki.

The most important anthropogenic metal sources are from metalliferous mining, agricultural activities, fossil fuel combustion and the metallurgical industries. Two large metallurgical units in central Hellas use the coastal area to dispose of metallurgical waste; one in the Korinthiakos Gulf, and another in the north Evvoikos Gulf.

Agriculture

Coastal agricultural land covers 35% of the total coastal land. These areas are of high productivity and suitable for all kinds of cultivation. Agricultural activities, especially in the lowlands, contribute to the following:

a) supply of water with nutrients and pollutants (POPs) through the drainage system,

b) change of sediment equilibrium (coastal supply and erosion) through the decrease of sand delivery to the coasts and canalisation of the rivers.

a) High levels of nutrients may lead to eutrophication and sometimes to algal bloom events. The coast most influenced by agriculture activities is the deltaic coast e.g. the coast of the northwest Thermaikos Gulf, where large rivers (Axios and Aliakmon) outflow. During the period 1995-2002 the nutrient concentration in the sea water, has shown an up to more than five times higher concentration of phosphates compared to the Thermaikos shelf sea, three times higher concentration of silicates, six times higher for ammonium and twenty times higher for the chlorophyll-a, (PAGOU *et. al.,* 2003). For other examples and more details see Chapters IV.1 (nutrients), IV.4 (POPs).

b) Agriculture indirectly influences the coast through the extraction of water from the rivers for irrigation. As a result of this the transport capacity of the river has been decreased, which leads to the reduction of sand delivery to the coast. The sediments' equilibrium between supply and long shore transport has been tipped out of balance; coastal erosion starts to dominate. Related to this aspect are the canalisation and the deviation of the riverbed in the deltaic areas for the better use of the land and of the water. Some sand barriers, which were formed during earlier and relatively pristine conditions, are nowadays exposed to the destructive force of waves. The role of sand barriers to separate some lagoonal systems is threatened. This seems to be the case in western Hellas, e.g. in the Acheloos river mouth. After the deviation of the river mouth of the Acheloos, during the 1930s, the sand barriers, which separate the lagoonal systems of Messolongi are now threatened from erosion. Some constructions were made to protect the sand barriers from erosion; but the natural character of the sand barriers is changed.

Figure VIII.3:
Elefsis Bay to the west and the basin of Athens to the east.

Aquaculture

In the last two decades Hellas has experienced a rapid development of marine aquaculture. Marine aquaculture activities take place in the sea near the coast. The infrastructure needed to support these activities is also located on the coast. To avoid conflicts with other anthropogenic activities fish farmers choose isolated areas near rocky coasts.

Deltaic coasts are usually used for the installation of the mussel farming units. The deltaic zone of the northwest Thermaikos Gulf, in the delta areas of the Axios, Loudias and Aliakmon rivers are presently occupied by a large number of mussel farming units. Most of them are located east of the river mouth of the Axios River (Figure VIII.4). Impact of aquaculture on the marine ecosystem is addressed in detail in Chapter VIII.5.

Saltpans and salt production

Salt production is another human activity in the lagoonal areas of the coastal zone. There are several saltpans throughout the country. It is important to mention this activity in order to highlight the recent experience, which suggest a compatibility of salt production and environmental conservation. Saltpans are important environments for wintering or intermediate stops of migrating birds (Figure VIII.5).

Tourism

The Hellenic coast with its natural and cultural assets is the main attraction for a large number of tourists every year. The tourist industry has been rapidly developed during the last 40 years so that Hellas nowadays receives 14-15 million tourists yearly. More than 90% of the tourist activities are located on the coast. The dominant type of tourism in Hellas is mass tourism, strongly related to sun, sand, sea and food. However, the tourist density indices are in general lower than the average indices in the Mediterranean. If we accept the usefulness of these indices we can say that Hellas does not face serious problems. The areas that show rapid development of tourism are mainly the island complexes of the Aegean and Ionian seas.

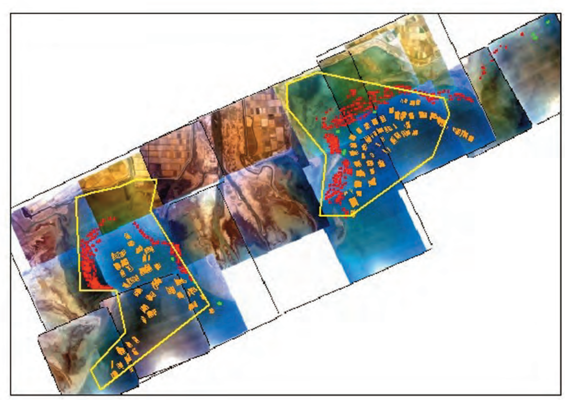


Figure VIII. 4:
Aerial photo showing the deltaic system of the Axios river in the north Thermaikos Gulf (northwest Aegean Sea) and the location of the mussel farming units (in red for the units using the pile installation technique, in yellow for the units using the floating technique).

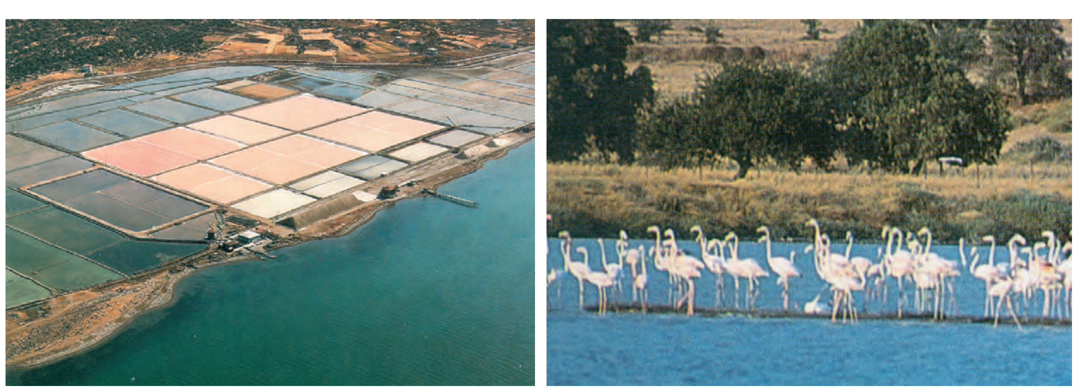


Figure VIII.5:
left: Saltpans and salt production in the Polychnitos lagoonal system (Lesvos Island); right: a bird community in a saltpan lagoonal system, suggesting the compatibility of salt production and environmental conservation.

A number of structures are designed to support tourism, which influence the coast, directly or indirectly: big hotels, roads, parks, boat launching ramps, piers, toilets and shower facilities, lifesaving clubs, refreshment kiosks, fixed umbrellas and sun loungers etc. (Figure VIII.6 and VIII.7).

Undoubtedly tourism development has led to economic profits. The contribution of this development to the improvement of the social state of the local societies is an open question.

Tourism related problems are not restricted only to urban changes but also to functional problems for the local inhabitants. Overcrowding of all services and of the beach sites, shortage of drinking water, waste disposal, noise levels and traffic congestion can be mentioned as typical of many tourist areas. These problems are often surpassing the organisational and financial capacity of local communities that must handle them. These problems occur because of the seasonal nature of the tourism, often during the summer period exceeding the capacity of both the natural and organisational system.

The 'second home' settlements for recreation

Many people, as a reaction to the centralised system of living in big cities need to have an

Figure VIII.6:
Big hotels built directly on the beach in order to support the tourist 'invasion' during the summer period on the island of Rodos.

Figure VIII.7:
Rodos, tourist facilities.

alternative, more relaxed life-style during the week ends and vacation times. They tend to build a 'second home' along the coast, causing very high pressure in coastal areas near Athens within a radius of 100-150 km as well near the city of Thessaloniki (Figure VIII.8).

About constructions on the coast

The construction on the coast generally intends to promote and protect economic and recreational interests. The most important coastal constructions are seawalls, breakwaters, groins and jetties.

Seawalls: Seawalls are vertical or sloping man-made constructions that are built along the shoreline on the coast in an attempt to protect the coast from erosion.

Breakwaters: Breakwaters are offshore constructions, which are designed to reduce wave energy and to form a protective harbour for moored vessels. In some cases they are designed to prevent the waves from eroding the shoreline.

Groins: Groins are constructions utilised to stabilise the coasts. They are made of the same materials used in seawalls and their purpose is to trap sediment that moves through the littoral drift system.

These constructions disrupt the configuration of the coast and there are often objections to proposals to build them. The reasons for these objections are aesthetic and ecological. The strongest argument against some of them is the understanding that although they are designed to protect the coastline from some natural phenomena they create new problems, which lead to a new designs, in order to protect the coast from the problems created by previous constructions.

Lately, this situation has led scientists to change their thinking in relation to coastal constructions that is, moving towards the use of **soft** means for coastal protection instead of **'hard'** constructions.

Constructions are the engineering response to coastal problems. The methods which include soft means for the coastal protection are not part of the engineering educational system. The engineers are anchored to the traditional type of hard constructions. They are not familiar, for example, with the technique of beach nourishment or dune stabilisation. These techniques avoid the use of material foreign to the coastal environment and preferably use natural materials, which are chosen for their aesthetic appearance and their compatibility with natural coastal processes.

Examples of constructions along the Hellenic coastlines

The purpose of this paragraph is to give some examples of unsuccessful constructions on the Hellenic coastline, on the one hand to document the objections against the one-dimensional design vision of the engineers, mentioned in the previous text and, on the other hand, to contribute to the discussion of how we can effectively face some problems related to the protection of the coastline (Box 1, Box 2).

In both above-mentioned examples, the construction of small ports acts as a 'dam' in the longshore transport of the beach sands. The sea wall separates an area suffering from erosion, from another area characterised by accretion. In both areas engineering measures were undertaken, on the one hand, to protect the coast from erosion and on the other hand, to protect the port from sediment accumulation. These measures were taken against the effects of erosion and accumulation and included mainly hard protective structures, such as wave walls and groins. This type of action had the main goal to protect mostly the economic values of the coastal area. However, the beaches did not improve.

Figure VIII.8: *'Second home' settlements for recreational use of people living in big cities.*

Both examples demonstrate how erroneous it is to believe that using various structures is the appropriate tool to manipulate the behaviour of nature and show us that the best way is to adapt the protection measures to the dynamics of the nature. Quality of human life and ecological values were absent from the design concept of the management strategy.

Box 1: *Constructions on long sandy beaches of Pieria*

The beaches of Pieria are located in the western part of the Thermaikos Gulf. This coastal area is characterised by extended sandy beaches, with a length of 15 to 20 km, which have been formed as a result of the interaction of the small rivers and tributaries' discharges and the dominant waves, from a SE direction. During the second half of the 20th century, the coastal area of this region was progressively developed as a tourist resort area. To support this development, a small port was constructed in the 1980s (Figure VIII.9).

Figure VIII.9: *Aerial photograph of the coast of Pieria showing the constructions in the small port and the 'chain' of the groins constructed for the protection of the beaches from erosion.*

The man-made constructions have led to the erosion of the most important part of the beach of this area. During the end of the 1980s and at the beginning of the 1990s, measures were undertaken along the coastal area to protect it from erosion. Five groins were constructed using natural stones (Figure VIII.9). These constructions prevented erosion in the parts of the coastline lying between them, but not the degradation of the beaches. The erosion continued in the non-protected coastline areas. New groins were constructed (up to 10 groins) without a positive result. The erosion continued to affect the non-protected areas. On the other hand, sand accumulated on the south side of the small port.

Summarising, we can say that the protection measures, which are still in progress, had a significant economic cost but no satisfactory results for the sustainability of the natural resources.

Box 2: *Constructions on the sandy beaches of Kato Achaia (northwest Peloponnisos)*

In Kato Achaia, northwest Peloponnisos, sandy beaches were formed by the sediment supply of the river Peiros. At the end of the 1970s a small port was constructed to support fisheries' activities of the area (Figure VIII.10).

Figure VIII.10:
Anthropogenic constructions on the sandy beaches of the Kato Achaia coastline.

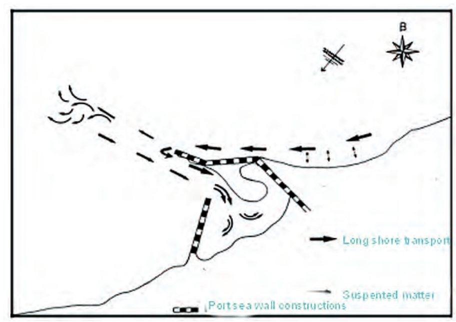


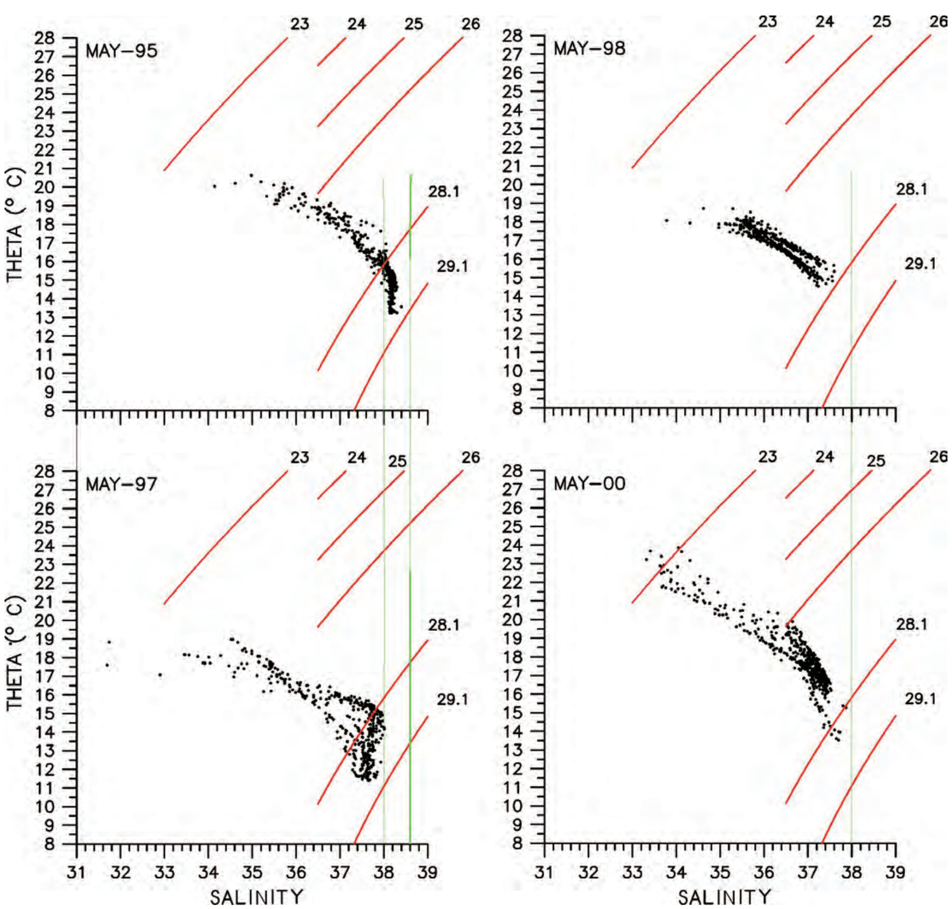
Figure VIII.11:
Long shore sediment transport dynamics and accumulation of suspended matter in the basin of the fisheries port of Kato Achaia.

The port construction had a negative result, the rapid accumulation of beach sediments to the east of the construction. The fine sediments bypassed the wave wall and were deposited in the basin of the small port, creating problems for the fishermens' boats (Figure VIII.11). At the same time, erosion started westerly of the construction, creating some serious problems to a relatively large hotel in the area. To avoid the accumulation of sediments in the port basin, new constructions were undertaken in the 1980s, extending the former wave walls, which solved the problem of sediment accumulation for a short time. New construction and installation of groins during the 1990s formed the modern type of man-made constructions in the area (Figure VIII.10). To avoid erosion in front of a big hotel in the area large rocks were placed there, changing the physiognomy of this area.

VIII.2. TRENDS IN HYDROGRAPHIC FEATURES

The coastal waters around the Hellenic territory are subjected to anthropogenic impact and apart from responding to trends in the physical forcing they also respond to trends associated with human activities such as pollutant input and control on the fresh water input by rivers.

The Thermaikos Gulf is a typical case where the fresh water input into the sea is greatly governed by human intervention on the river water for agriculture and for hydroelectric power generation. Figure VIII.12 presents t/s diagrams during May 1995, May 1997, May 1998 and May 2000 in the northernmost area of the Thermaikos Gulf (north of ~40.48˚ N), called the Gulf of Thessaloniki. The salinity in the deeper layers in Thessaloniki Bay, which corresponds to the lower-deep temperatures observed in the t/s diagrams, shows a systematic decrease from 1995 until 2000. KONTOYIANNIS & KARAMANOS (2000) have provided observational evidence that the near bottom salinities in the Gulf of Thessaloniki, which are governed by the saline intrusions of Aegean water, are strongly correlated with the river input in the upper layers. The more fresh water that is added to the surface layer by the rivers, the more deeply into the gulf the subsurface Aegean saline tongue progresses.



Source: *KONTOYIANNIS & KARAMANOS (2000).*

Figure VIII.12: *Temperature/salinity (T/S) diagrams in the Gulf of Thessaloniki (Thermaikos Gulf north of 40.47˚ N) during May for the years 1995, 1997, 1998 and 2000.*

Therefore, the rivers play a significant role in the exchange of water masses between the north Thermaikos and the Aegean Sea. The inter-annual decrease in deep salinities in the Gulf of Thessaloniki, shown in Figure 13, is most likely due an inter-annual decrease in fresh water input, which is mainly caused by the increased human demand on the fresh water resources.

A second example of long-term variability in physical properties of coastal waters is drawn from observations in the Saronikos Gulf. Figure VIII.13 shows the vertically averaged Beam Attenuation Coefficient (BAC) at 37.84˚ N, 23.45˚ E in the Saronikos Gulf (Figure III.9) from monthly observations of a four-year monitoring period (May 2000 to June 2004). It should be pointed out that BAC is an indication of the transparency of sea water. Values of BAC around 0.8 correspond to conditions in water transparency such that a Secchi disk (white disk of ~40 cm diameter) is barely visible at depth 15-17 m by an observer at the surface, while for BAC values around 1.5 the Secchi disk is visible down to a depth of 3-4 m at most. Consequently, BAC is directly related to the amount of suspended solid material (particles) at the point of the BAC measurement (NCMR, 2001a).

In the Saronikos Gulf, an increasing trend of BAC appears from the start of the record in May 2000 to the end of summer 2003. Afterwards, and until the end of the record, the BAC curve levels off and there is also a slight indication of a probable decreasing trend. Knowing that there is no substantial river input of suspended solids into the Saronikos Gulf, a plausible explanation of the existing trends in the BAC curve is that they are mostly driven by atmospheric input of solids (dust) generated by the overall constructions for the Olympic Games of summer 2004. Most of the major excavations for these works took place prior to 2004, a lot of the constructions were along the waterfront and the dust was transported into the gulf by northerly winds that are predominant throughout the year in this area.

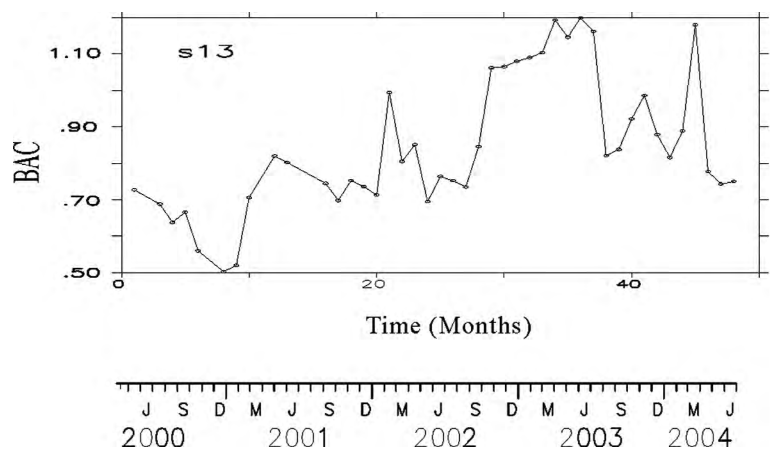


Figure VIII.13:
Time- series of vertically averaged Beam Attenuation coefficient at site S13 (south of Psittalia Island, Figure III.9) in the Saronikos Gulf. Solid points represent monthly site observations.

VIII.3. EUTROPHICATION IN HELLENIC COASTAL AREAS

By definition eutrophication is the process by which waters enriched with nutrients, primarily nitrogen and phosphorus, under favourable physico-chemical conditions stimulate aquatic primary production.

Nutrients in the appropriate (i.e. background levels) amounts are essential to maintain an adequate primary productivity, which in turn is essential to support all other trophic levels in the ecosystem. In general, excessive nutrients cause acceleration of phytoplankton growth rates and increased phytoplankton biomass, often dominated by harmful or toxic species. Thus an imbalance exists between the processes of algal production and consumption, resulting in algal blooms, followed by sedimentation of algal derived organic matter, stimulation of microbial decomposition and oxygen consumption with depletion of bottom-water oxygen in stratified water bodies. In permanently stratified water bodies, deep water anoxia/hypoxia can also be purely natural phenomena. Furthermore, eutrophication causes changes in community composition and abundance directly and indirectly by decreasing light penetration into deeper water layers. Finally, algal scum, enhanced benthic algal growth and at times a massive growth of submerged and floating macrophytes and fish kills are reported among the most serious consequences. Thus, eutrophication not only causes nuisance increases in plant growth but also losses in ecosystem component species, as well as losses in amenities and/or services.

The eastern Mediterranean is one of the world's poorest seas. The Hellenic Seas seem to be among the most oligotrophic marine areas. A number of recent studies in the Aegean Sea confirmed its oligotrophic status (IGNATIADES *et al.*, 2002, see also Chapter V.5). Despite the above, eutrophication problems have been recognised in a number of Aegean and Ionian coastal areas, affected by urban and industrial wastewaters and/or nutrient inputs from rivers and agricultural activities (PAGOU & IGNATIADES, 1988, 1990; IZZO & PAGOU, 1999; MONCHEVA *et al.*, 2001).

The most disturbed Hellenic coastal areas, regarding anthropogenic nutrient enrichment, are the Saronikos and Thermaikos gulfs situated in the central and northern Aegean Sea, respectively. Other areas that are reported to present eutrophic or mesotrophic conditions are: the Pagasitikos Gulf, the Alexandroupolis Gulf, the Kavala Gulf, the Amvrakikos Gulf, the Kalloni and Geras gulfs, the Argolikos Gulf and lagoons, such as the Araxos lagoon in the western Peloponissos, the Vassova lagoon on the Makedonian coast in northern Hellas, etc. (see also Figure V.9 in Chapter V.5).

EUTROPHICATION ASSESSMENT CRITERIA USED FOR HELLENIC COASTAL AREAS

Eutrophication is addressed in several EU policies, as:

- Nutrient levels to describe the water quality were introduced in several early pieces of EU water legislation (e.g. Freshwater Fish Directive 78/659/EEC).
- The Urban Wastewater Treatment Directive (91/271/EEC) addresses the major point sources, in particular the municipal wastewater discharges.
- The Nitrates Directive (91/676/EEC) deals with the diffuse pollution of nitrogen from agriculture.
- Furthermore, eutrophication is indirectly addressed in the Dangerous Substance Directive (76/464/EEC) that lists inorganic phosphorus and substances, which have an adverse effect on the oxygen balance, particularly ammonia and nitrites.

Among the above directives, the main anthropogenic sources of nutrient loadings were addressed in the two directives published in 1991 (91/271/EEC and 91/676/EEC). Both directives define the term 'eutrophication'. In addition, the designation of sensitive areas or vulnerable zones (which suffer from eutrophication or may suffer from it, if measures are not taken) in the UWWT and Nitrates Directives provide for measures to combat eutrophication.

Hellas, in order to implement the requirements of the above directives, successfully adopted and applied the eutrophication assessment criteria described below, which are methodological procedures developed for the eastern Mediterranean coastal areas and used in order to define eutrophication scales, assign critical values and, consequently, evaluate water quality.

However, it must be noted that, in 2000, the WFD (2000/60/EC) introduced, amongst other requirements, a comprehensive ecological quality assessment for all waters, which describes the quality of the waters (looking at the whole water cycle in a holistic manner) with a number of biological, hydromorphological and physicochemical quality elements. The WFD provides a basis for a clear and detailed assessment of eutrophication and provides the potential for a more consistent and integrated approach to managing nutrient inputs into water, taking fully into account the requirements of previous EU legislation. Under the Common Implementation Strategy of the WFD and the European Marine Strategy, an activity was initiated in order to provide guidance on the harmonisation of assessment methodologies and of criteria for agreed eutrophication elements/ parameters/ indicators. Hellas is participating actively in this initiative.

A. EUTROPHICATION SCALE BASED ON NUTRIENT AND PHYTOPLANKTON DATA:

Definition of concentration ranges from nutrient and phytoplankton data sets, specific for this region of the eastern Mediterranean and characteristic of the different trophic levels in the Hellenic Seas have been conducted by local authorities in several Hellenic gulfs. A eutrophication scale was developed by IGNATIADES *et al.*, (1992) and KARYDIS (1999), based on nutrient data from several Hellenic marine areas (coastal and offshore) influenced or not by industrial and/or domestic effluents. Later the original eutrophication scale was modified in order to also include phytoplankton parameters (SIOKOU-FRANGOU, & PAGOU, 2000), which underwent the same statistical treatment. The derived eutrophication scale is given in Table VIII.1.

Four levels of eutrophication are defined in this scale: eutrophic, higher mesotrophic, lower mesotrophic and oligotrophic. These levels could be considered as corresponding to the five categories of environmental status as defined by the WFD: eutrophic for bad, higher mesotrophic for poor and moderate, lower mesotrophic for good and oligotrophic for high. In addition, nutrient concentrations, which define higher mesotrophic conditions indicate ‘sensitive’ ecosystems (can be eutrophic in the future, if an increasing trend in eutrophication parameters is detected).

B. THEMATIC MAPS:

The methodological procedure for the generation of thematic maps regarding the spatial distribution of each nutrient and chlorophyll or the synthesis of all measured parameters was based on the application of the spatial interpolation Kriging method (LANCASTER & SALKAUSKAS, 1986). The method was applied in a spatial resolution of 100x100m using Geographic Information System (ARC/INFO version 7.1.2). The values of each generated continuous surface were categorised, based on the nutrient and chlorophyll concentration scaling given in Table VIII.1. Therefore, four levels of eutrophication were defined on the thematic

Table VIII.1: *Trophic classification ranges based on nutrients (phosphates, nitrates, ammonium), chlorophyll α and total number of phytoplankton cells. Nutrients concentrations are given in μM, phytoplankton cells number in cells l^{-1} and chlorophyll in μg l^{-1}.*

Parameter	Oligotrophic mesotrophic	Lower mesotrophic	Higher	Eutrophic
Phosphates (PO_4)	<0.07	0.07-0.14	0.14-0.68	>0.68
Nitrates (NO_3)	<0.62	0.62-0.65	0.65-1.19	>1.19
Ammonium (NH_4)	<0.55	0.55-1.05	1.05-2.2	>2.2
Phytoplankton	$<6x10^3$	$6x10^3$-$1.5x10^5$	$1.5x10^5$-$9.6x10^5$	$>9.6x10^5$
Chlorophyll α	<0.1	0.1-0.6	0.6-2.21	>2.21

maps: eutrophic, higher mesotrophic, lower mesotrophic and oligotrophic. For the synthesis of all measured parameters to create the final eutrophication map the limits of each trophic level of Table VIII.1 were standardised. Standardisation is necessary in order to compare and combine parameters-criteria measured in different scales, as are nutrients and chlorophyll α.

C. TREND ANALYSIS:

The investigation of the existence of trends in the evolution of the trophic condition parameters and nutrient ratios is very important, both for the assessment of the eutrophication levels and also in order to test the effectiveness of management plans applied in coastal and marine areas.

CASE STUDIES

Eutrophication conditions and assessment will be presented in detail for the two most studied Hellenic coastal areas: the Saronikos and Thermaikos gulfs. The main environmental pressures affecting both areas have been identified in Chapter IV.3A.

A. EUTROPHICATION SCALE BASED ASSESSMENT:

The application of this criterion showed that overall the inner Saronikos Gulf (the sewage receptor water body) revealed a high mesotrophic character regarding nutrients and phytoplanktonic cells and low mesotrophic regarding chlorophyll α. A small area of its southern part is oligotrophic, whereas the northern part (Keratsini Bay) is high mesotrophic (Table VIII.2).

On the other hand, the northern part (port and sewage outfall area) of the inner Thermaikos Gulf has a higher mesotrophic to eutrophic character (depending on the parameter), whereas estuaries can be characterised as mesotrophic (towards the upper levels). The central and southern parts of the inner Thermaikos Gulf has a variable character from oligotrophic to higher mesotrophic, depending on the parameter. It must be mentioned again that this is not a deficiency of the examined tool, but different parameters have different spatial behavior (Table VIII.3).

Table VIII.2: *Mean annual values based on mean integrated values (May 2003 - May 2004) of the studied parameters in the water column. Symbols: EU=Eutrophic, HM=Higher Mesotrophic, LM=Lower Mesotrophic, OL=Oligotrophic.*

Area	PO_4 (μgat/l)	NO_3 (μgat/l)	NH_4 (μgat/l)	Chl-α (μg/l)	N/P
Elefsis Bay	0.33 HM	1.90 EU	1.49 HM	0.84 HM	11.4
Keratsini Bay (former outfall)	0.29 HM	0.96 LM	0.91 LM	0.57 LM	7.61
Psittalia (new outfall)	0.33 HM	0.85 HM	1.45 HM	0.35 LM	8.10
Inner Gulf (8.5 km to the SE from new outfall	0.19 HM	0.89 HM	0.36 OL	0.31 LM	8.04
Inner Gulf (15 km to the SW from new outfall)	0.22 HM	1.09 HM	0.34 OL	0.18 LM	7.73
Southern Inner Gulf (18 km to the SE from new outfall)	0.15 HM	0.42 LM	0.17 OL	0.18 LM	5.11

Table VIII.3: *Mean annual values based on mean integrated values of the studied parameters for the period May 1997-May 1998 in the water column. Symbols: EU=Eutrophic, HM=Higher Mesotrophic, LM=Lower Mesotrophic, OL=Oligotrophic.*

Area	PO_4 (μgat/l)	NO_3 (μgat/l)	NH_4 (μgat/l)	Chl-α (μg/l)
Thessaloniki Bay - port	0.45 HM	1.04 HM	1.63 HM	3.79 EU
Thessaloniki Gulf - outfall	0.34 HM	1.08 HM	1.64 HM	2.37 EU
Estuaries0.33 HM	1.59 EU	0.77 LM	1.67 HM	
Inner Thermaikos Gulf	0.10 LM	0.57 OL	0.93 LM	1.16 HM

B. PRESENTATION IN THEMATIC MAPS:

Nutrient loads tend to homogenise environmental gradients, whereas phytoplankton parameters show spatial heterogeneity (LI & REYNOLDS, 1994). Furthermore, according to LIPIATOU (2002) nutrient threshold is referring to the sum of organic and inorganic nitrogen and phosphorus and carbon and Si. Thus, a synthetic trophic condition presentation was produced for the Saronikos Gulf based on all available environmental parameters (Figure VIII.14). Taking into account the whole water column and the annual mean values, the inner Saronikos is characterised as high mesotrophic, but the southeastern part is low mesotrophic to oligotrophic. Elefsis Bay is shown to be eutrophic.

C. ASSESSMENT BY MEANS OF TREND ANALYSIS:

Trend analysis was performed in time-series (1987-2004) of nutrients, N/P ratios, chlorophyll and zooplankton biomass from the Saronikos Gulf (Figure VIII.15). Eutrophication trends did not present a consistent character, since a different trend was detected for nutrients (eutrophication causative), when compared to chlorophyll (eutrophication result). Increasing trends were found for most of the nutrients, whereas chlorophyll α revealed a general decreasing trend. The observed increasing trends of nutrients in the sewage outfall area can be interpreted by the increase of the discharge volume. Especially for nitrates, the increase observed at all sampling sites

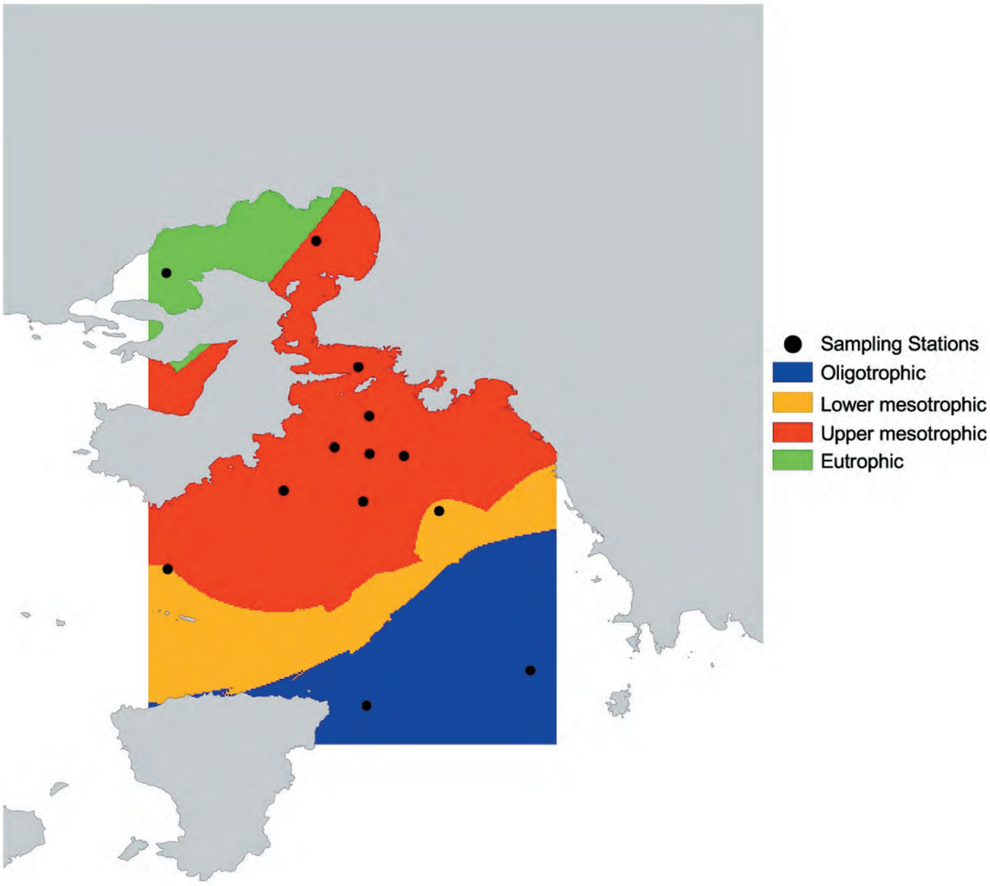


Figure VIII.14: *Eutrophication levels in the Saronikos Gulf according to the synthesis of all examined parameters (May 2003-May 2004).*

Source: *HCMR, 2005.*

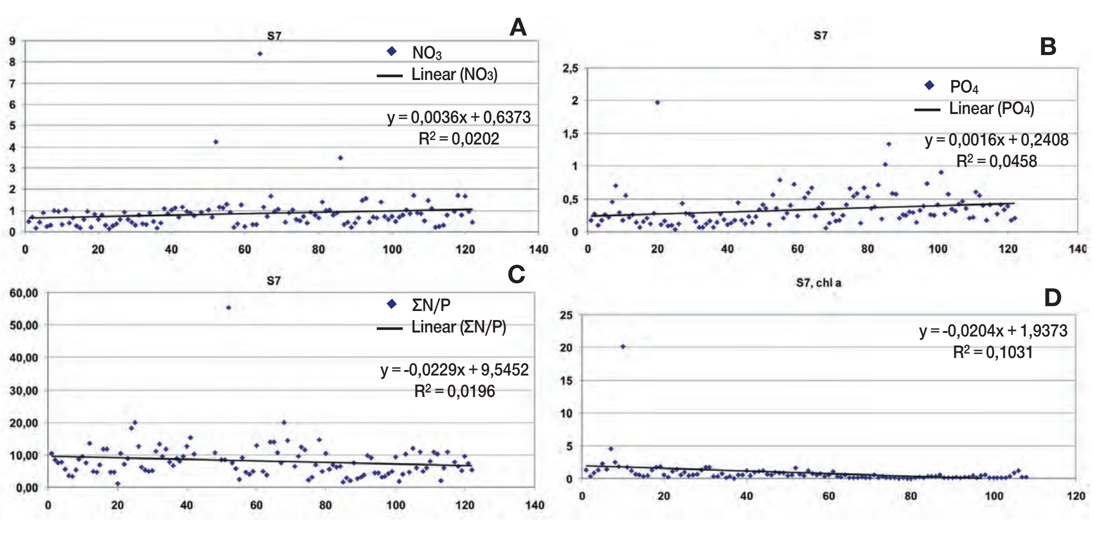
Note: *Annual means of mean integrated values over the water column.*

could be related to the discharges increase and diffusion due to circulation patterns. Entrance from the atmosphere should also be considered (CARPENTER *et al.*, 1998). However, the decreasing trends of chlorophyll *a* concentrations suggest that nutrients (and mainly nitrates) are not exclusively used by the autotrophic organisms (heterotrophic bacteria also use nutrients). On the other hand, non favourable relative concentration ratios in the sewage area (N/P, Si/N, Si/P), or even light limitation, since sewage is discharged at a greater depth than before 1994, should also be encountered. Furthermore, a significant factor is the effective consumption of phytoplankton by zooplankton, suggested by the increasing trends of zooplankton biomass.

Before the operation of the Psittalia treatment plant (1994) the highest chlorophyll values were recorded in the surface layer, whereas surface and column integrated values are very low after 1994 (NCMR, 1999; HCMR, 2005). At this point the decreasing trend found regarding N/P ratios in the inner Saronikos (except Elefsis Bay) in opposition to the trend found until 1999, must be mentioned.

Trend analyses of nutrients and chlorophyll time-series from the Thermaikos Gulf revealed also some important features (Figure VIII.16). Nutrients and chlorophyll *a* concentrations showed a general trend to decrease during the last years, according to the trend analysis performed in time-series data from 1993 to 2000. These decreasing trends were often statistically significant. However, an exception was recorded. In the reference area some of the nutrients (nitrate and ammonium) showed a not statistically significant increasing trend, whereas phosphate concentrations remained stable. The reference area was near the southern boundaries of the inner Thermaikos with the outer gulf where it is assumed there is a minimum impact from the sewage. Therefore, the existence of a local inflow of nutrients is suggested, which can possibly be of a local nature. This increase needs further investigation. In conclusion, nutrients and chlorophyll concentrations show a decreasing trend in the most affected areas of the inner Thermaikos Gulf during the last years (1993-2000).

In the Thermaikos Gulf the frequent diatom blooms observed before 1996 changed to even noxious dinoflagellate blooms that can be related to the very low N/P ratios recorded at the northern part of the inner Thermaikos Gulf, the site where the exceptional blooms usually have started (Figure VIII.17). Trend analysis of N/P ratios in the inner Thermaikos Gulf from 1993 to 2000 showed that in Thessaloniki Bay where the port is situated, there was no trend and N/P ratio values were very low, with seasonal means that did not exceed 12. South of the port, in the area where the new sewage outfall is discharging an area with many mussel



Source: *HCMR, 2005*
Note: *Mean integrated values for the water column.*

Figure VIII.15: *Trend for the fitted model, after the regression analysis, for selected time-series of A) nitrates, B) phosphates, C) N/P ratio and D) chlorophyll a, at the sewage outfall area of the Saronikos Gulf.*

cultures nearby, N/P is showing a decreasing trend. Finally, in the estuaries area N/P ratio showed an increasing trend until 2000. Variability in all areas was irregular and abrupt. However, during the period 2000-2004 very low values were recorded again (even lower than 5). These trends should be related to changes in river discharges and rainfall in the different years.

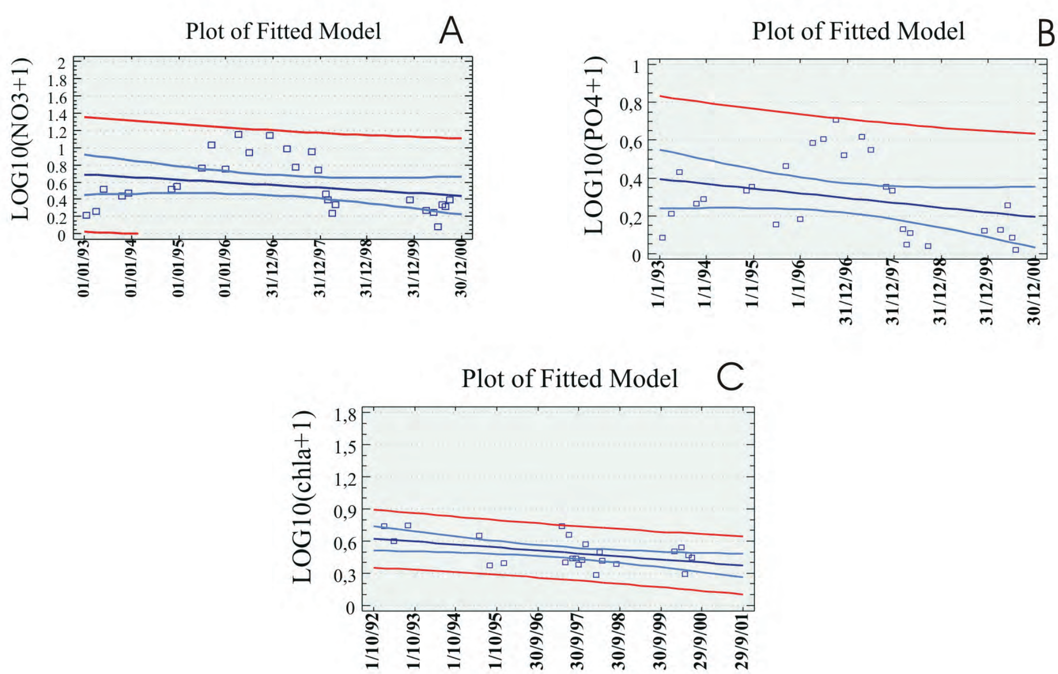


Figure VIII.16: *Trend for the fitted model, after the regression analysis, for selected time series of A) nitrates, B) phosphates and C) chlorophyll a, at the sewage outfall area of Thermaikos Gulf.*

Source: *PAGOU et al., 2003*

Note: *Mean integrated values for the water column.*

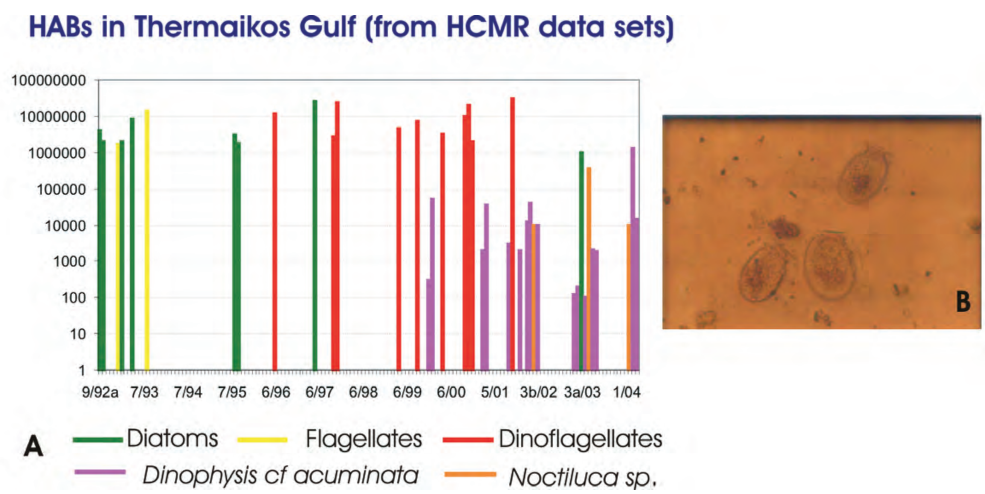


Figure VIII.17: *A. Harmful Algal Blooms in the Thermaikos Gulf, including toxic events caused by B. Dinophysis cf. acuminata (NIKON inverted microscope, magnification >X50000).*

Source: *PAGOU et al., 2004; PAGOU: unpubl.data.*

These extremely low values of N/P can be attributed, not only to sewage enrichment, but also to additional enrichment through the river freshwater inflow. Orthophosphate input in the Thermaikos Gulf from the rivers is at the same range and higher than that of the Rhone River in the Gulf of Lions, thus confirming the statement in the European Environment Agency report (EEA, 1999), that phosphate concentrations have increased dramatically in Hellas. Furthermore, when calculating budgets of non conservative materials for the Thermaikos Gulf during winter and spring, ΔDIP (non conservative Dissolved Inorganic Phosphorus flux) was found to be positive, indicating that there is a net release of DIP (Dissolved Inorganic Phosphorus) probably related to organic matter regeneration processes (PAGOU *et al.*, 2001).

HARMFUL ALGAL BLOOMS (HABs)

As it was mentioned above and in Chapter V.2 for red tides, Thermaikos Gulf is an area where HABs are recorded frequently (Figures VIII.17, VIII.18). Dinoflagellates were the dominant blooming species from 1996 and among them was the toxic species *Dinophysis cf. acuminata*, a DSP causative (Diarrhoeic Shellfish Poisoning), with substantial socio-economic impact in the area (economic losses of ~3 million Euros every year). The first confirmed 'bloom' of *Dinophysis cf. acuminata* was recorded from January to May 2000. This one was of the most severe, with toxic cell abundances >50 000cells L^{-1} and Okadaic Acid concentrations up to 1 600ng g^{-1} of mussel tissue (8 times higher than limits). The *Dinophysis cf. acuminata* blooms were repeated the following years during spring and reached 1.0X106 cells L^{-1} in March 2004 (PAGOU *et al.*, 2004).

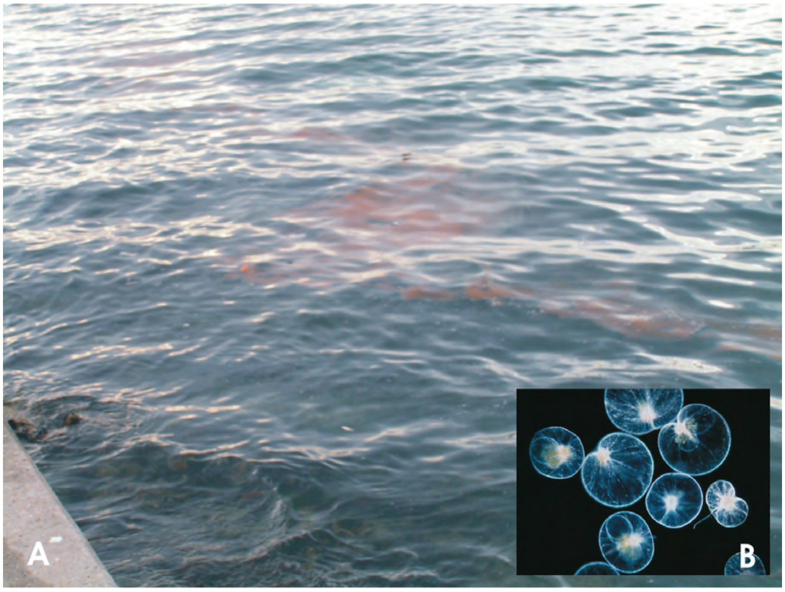


Photo: *A. SOUPILAS.*

Figure VIII.18:
Red tide in the Thermaikos Gulf during February 2005 (A), due to Noctiluca sp.(B)

VIII.4. ENVIRONMENTAL IMPACTS OF FISHERIES

A major effort, particularly in the last 10 years (HALL, 1999; KAISER & de GROOT 2000) has been put into investigating the environmental impact of fishing and more recently, into the ecosystem effects of fishing.

The issue of ecosystem effects is very complicated primarily due to the complexity of the environment (the multitude of dependencies of different relationships) and also because of the wide diversity of different types of capture methods and their different intensities (Figure VIII.19). Faunal impacts can be broadly classified in two categories: (1) effects at the community level and (2) effects at the level of individual species. The effects at these two levels, which can be direct or indirect, strongly interact with each other in a complex and often unpredictable manner.

Direct effects include:

1. Fishing mortality on species populations (target commercial and non-target species) during the fishing process, either by removal (to land or to discard) or by killing them without actually retaining them in the gear (non-catch mortality), and/or by making them vulnerable to scavengers and predators (through exposure and damage).
2. Energy subsidies and increasing food available to other species in the system by discarding unwanted fish, fish offal and benthos.
3. Physical disturbance and/or loss of marine habitats, e.g. by altering the seabed surface topography or by destroying coral reefs and maerl habitats.

Indirect effects are the knock-on effects that follow from a direct effect, including:

1. Effects on diversity, abundance and body-size, alterations of benthic community function and structure.
2. Species interactions and predator and prey responses to the removal of target species.
3. Sediment resuspension, nutrient regeneration and effects on biochemical processes.

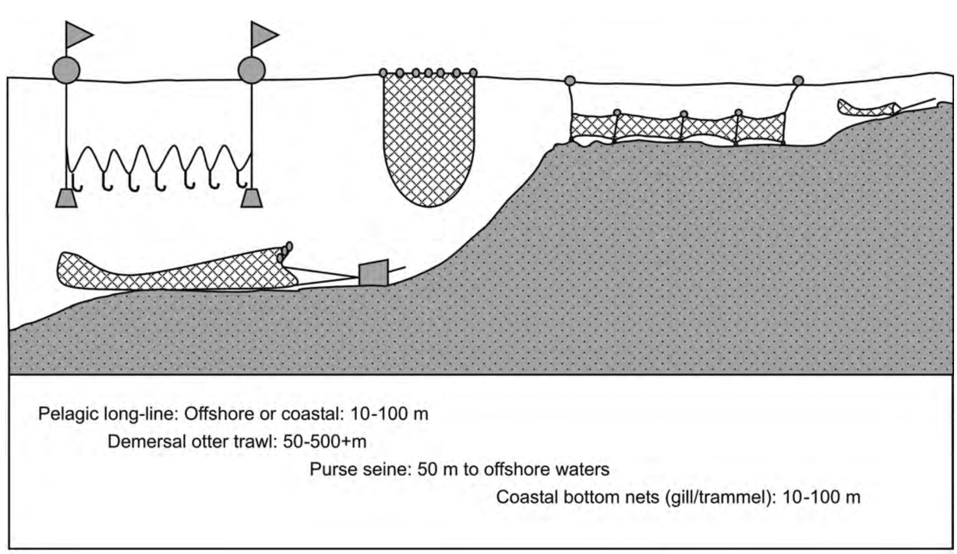


Figure VIII.19: Species removal from the ecosystem in different depth ranges.

A substantial number of projects, supported by the European Union and the Hellenic General Secretariat for Research and Technology, have been carried out recently in Hellenic waters. A certain amount of work has been published in scientific journals, although the majority of it is in the grey literature or still to be published. There is a large amount of work still to be done and this is highlighted later, by gaps in the knowledge. The studies that have been completed to date fall into several major categories although multiple aspects may have been completed in a particular study. These include both experimental and monitoring studies, i.e. a) BACI (Before After Control Impact) studies where experimental trawling is carried out in small defined areas and similar adjacent control areas, to look at initial impacts and recovery and b) comparative studies of commercially trawled areas over time (during the open and closed season for trawling) and/or with similar untrawled areas.

Fishing gears

Fisheries in Hellas are restricted to a number of active and passive gears. Small and medium sized pelagic fish are normally captured with enclosing purse seines (pelagic trawling is forbidden). Large pelagic species are fished with long lines (drift nets are forbidden). The largest recorded landings of demersal fish are from the trawling, with trawlers operating from 50 m inshore to 500+m depth offshore. Beach seines, a type of mini trawl operated in shallow coastal waters, are used in a few areas, but licences are being withdrawn to protect shallow habitats. The largest number of boats is involved in artisanal fisheries, using mostly gill and trammel nets and to a lesser degree, traps. On the whole, passive gears (e.g. long lines) have little impact when compared to active gears (e.g. otter trawl). The gear contact area is zero (e.g. long lines, purse seine) or small (nets), though the removal power of the Hellenic artisanal fleet through its shear size, is a major force in coastal waters. Of the active gears (e.g. beam trawl, dredges, otter trawls), otter trawling, although more wide spread, has less initial effects on the biota (COLLIE *et al.*, 2000). The contribution of bottom trawling to the total amount of discards is, however, the highest.

Discards

Although some information is available for discard to landed catch ratios the fate of discarded individuals is still largely unknown in the Mediterranean. Of the discards, a percentage will have died even before being landed on the vessel (suffocation, crushing, and gear injuries) whereas another percentage will die on the vessel (aerial exposure, mechanical action, thermal shock). Approximately 44% of commercial Hellenic trawl catches are discarded at sea, which represents some 13.500-22.000 tonnes annually ('DISCARDS' project). Although there is no information on numbers or survival of fish that pass through the net, an equal quantity is expected to die. Discards typically include fish (non-commercial, undersized commercial and low market value commercial species), and non-commercial invertebrates (crustaceans, echinoderms and cephalopods).

Data on discards by species and weight per taxon are obtained from seasonal monitoring of the discarding practices of commercial trawlers for depths up to 500 m (Table VIII.4). These practices depend on area, season, fishery regulations and market prices. For example, highest discarded yields are usually seen in autumn, especially for fish and crustaceans, while lower cephalopod discard quantities were seen in the Ionian Sea. Furthermore, the discarded fraction for fish increases with depth, whereas the discarded biomass decreases (larger but fewer individuals and less commercial species). Up to

Table VIII.4: *Aegean-Ionian: % discards by weight, Ionian: % non-commercial species by weight, Total: total catch of fish, crustaceans and cephalopods.*

	Aegean-Ionian	Ionian		
	0-500m	300-500 m	500-700 m	700-900 m
Fish	34-44	56-75	27-51	63-79
Crustacea	48-91	15-31	02-05	02-04
Cephalopoda	11-31	12-42	14-100	39-86
Total catch	39-49	52-71	22-40	55-65

Source: *Aegean: MACHIAS et al., 2001 ('DISCARDS'). Ionian: POLITOU et al., 2003 ('INTERREG').*

now, data on deep water non-commercial, potentially discarded, species are obtained through experimental work ('MEDITS' and 'INTERREG' Projects). As the quality and quantity of discards are gear and ground specific, quantification of discards alone is a poor indicator of the effects of fishing on biological communities. Ground and fishery specific data on damage, survival and fate of discards could indicate selective pressure on certain vulnerable epibenthic organisms or functional groups shifts in community composition (e.g. through influx of scavengers and survivors favoured by increased carrion) and would be important considerations in any fishing effort management scheme.

Mortality during trawling

Fishing mortality during the fishing process on target commercial, non-target undersized commercial species and non-commercial species occurs, either by removal (landed and discarded catches) or as non-catch sea bed mortality by killing species without actually retaining them in the gear (Figure VIII.20). Capture will depend on mobility, body size and shape, and position (sediment surface dwelling or deep burrowing). Damage and survival is species-specific but exposed and damaged species will be vulnerable to predation resulting in lower survival rates. The 'OTIP' project investigated 14 species of echinoderms, reporting average damage to be around 60% and serious near lethal damage around 15% of the catch.

Direct species interactions during trawling

Bottom trawls sweep a line of seabed (Figure VIII.21). The line covered by the warps will herd a certain percentage of individuals in towards the mouth of the following net. This percentage depends to a large extent on the mobility of the individuals. A percentage of mobile individuals with escape responses will escape, for example, by swimming over the top of the gear. Once within the net some individuals may manage to escape through the meshes of the trawl. Not all escapees will survive, as movement through the mesh may cause damage. To minimise effects, the use of different mesh sizes and square mesh and escape panels is being investigated.

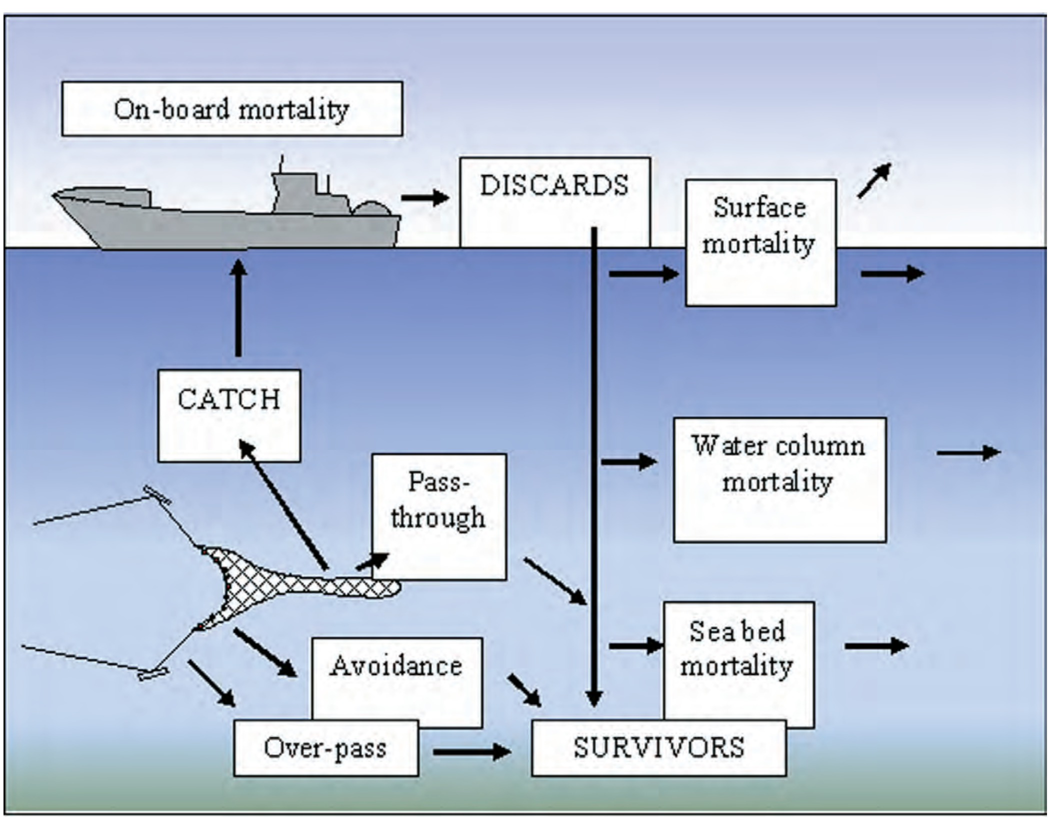


Figure VIII.20: *Survival, direct and indirect mortality due to trawling.*

Habitat Effects

As a trawl passes along the seabed it has contact with the seabed in a number of different ways. The trawl wires towing the trawl bend down and scrape the sediment surface. The otter doors that are attached to the trawl wires have a primary function in acting as kites to move out perpendicular to the direction of the tow and hold the mouth of the trawl open. Digging/ploughing and scraping has the effect of turning over the sediment surface. This activity has a direct effect on the infauna of the sediment. As well as damage and mortality from direct contact with the gear, some individuals may be exposed and liable to predation or others may be smothered or buried leading to secondary mortality.

Primary Environmental Effects from Physical Contact by the Trawl

- *Door marks:* the most distinctive feature, caused by the trawl doors; wooden or metal doors acting like wings, spreading the tow warps and keeping the mouth of the trawl open. Figure VIII.22 shows how trawl door marks can cover the sea bed, Figure VIII.23 an old trawl door mark ('OTIP' & 'COST-IMPACT') and Figure VIII.24 a photograph of sediment disturbance caused by a trawl door.
- *Wire scrape marks:* single or multiple parallel, non-continuous marks caused by the towing warps contacting the seabed, maybe noted in the herding zone. These may not be apparent in hard sediments

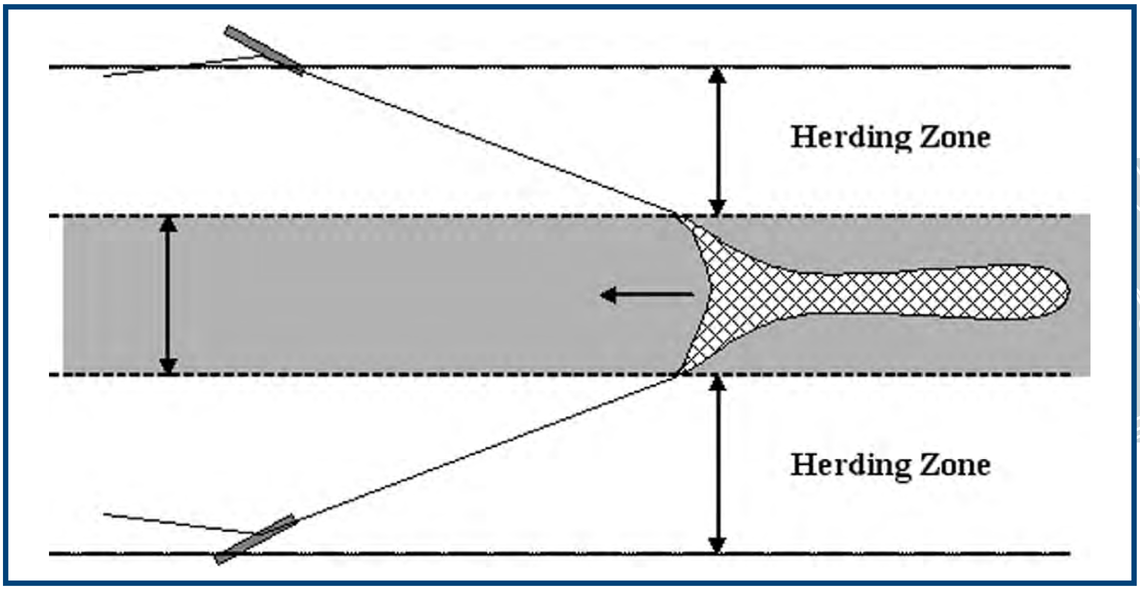


Figure VIII.21: *Coverage path for a bottom trawl.*

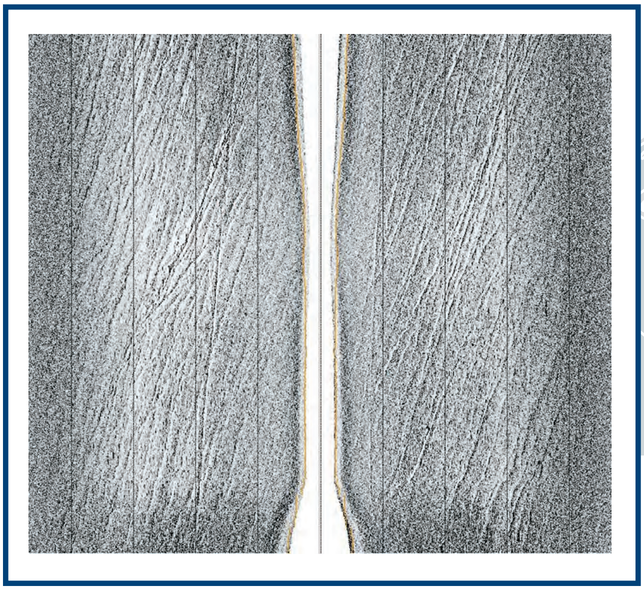


Figure VIII.22: *Side scan sonar image showing trawl door scrapes on the sea bed in the Aegean. Scale of view is approximately 200 x 200 m with in excess of 50 trawling marks diagonally crossing the image.*

- *Flattened areas:* Caused by the ground rope and belly of the trawl scraping over the sediment surface and flattening local microtopography in the trawl path.

Natural soft sediments can have a high degree of local microtopography caused by biological activity with feeding mounds, pits and burrow systems. Figure VIII.25 shows the natural microtopography in an untrawled area in close vicinity to a trawl lane in the southern Aegean ('COST-IMPACT'). Natural hard sediments have less local microtopography, but may be interspaced with areas of harder substrate (maerl, rock outcrops) as well as having more sessile epifauna.

Due to hydrodynamic and/or biological activity trawl marks will 'age' with time, hard edges will

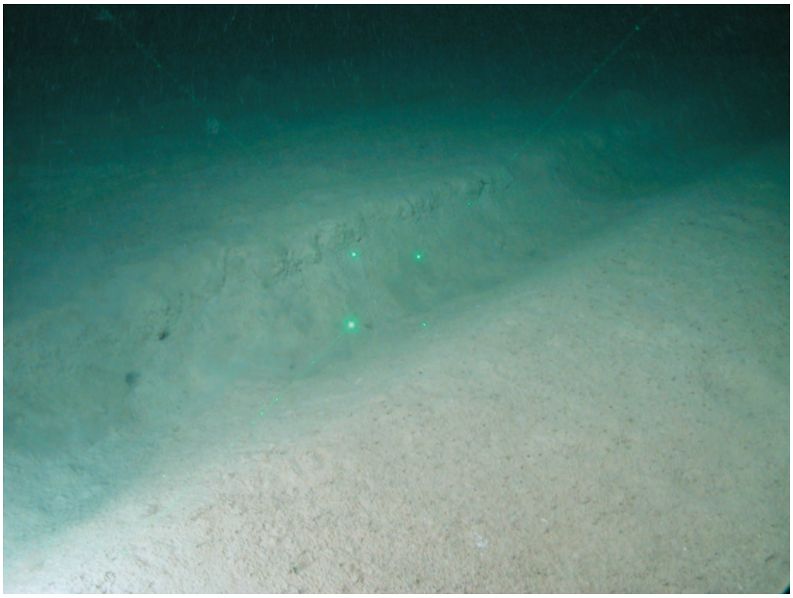


Figure VIII.23:
Old trawling mark caused by otter door with rounded edges; laser dots in the middle of the image 10 cm spacing.

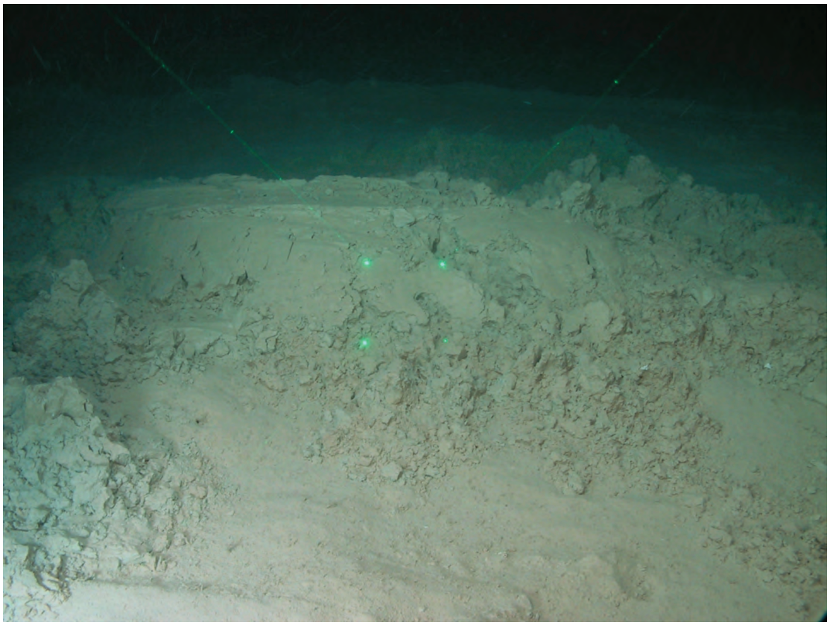


Figure VIII.24:
Freshly broken sediment heap caused by otter door; laser dots in the middle of the image 10 cm spacing.

soften and plough marks will gradually fill-in ('FGE' & 'OTIP' Projects, SMITH *et al.* 2000, COGGAN *et al.*, 2001). Continuous trawling in the same area will lead to fill-in and smoothing of older traces.

Secondary Environmental Effects from Physical Contact by the Trawl

In hard sediments trawling will lead to fragmentation of rock and biogenic substrata while in soft sediments trawling action is also responsible for a number of secondary disturbance effects:

- Resuspension of surface sediments and lighter sedimentary fractions. Sediment trap measurements ('INTERPOL') and trawling simulation experiments ('TRBIOGEO') indicate a significant increase of near bottom sediment resuspension during trawling
- Depending on diffusion and bottom currents, sedimentation of lighter grains may not be in the same area. An increase in fine grains in the deposition area may also cause smothering of some species; especially filter feeding animals with delicate feeding apparatus.
- Deeper sediments that are exposed tend to be more anoxic sediments and although they will be oxygenated by diffusion, they will form an inhospitable environment for recolonisation.
- There is evidence ('INTERPOL' & 'TRBIOGEO') that trawling will also release nutrients locked into sediments, which may be available for primary production in that area.

Lost Gear and Ghost Fishing

All fishing methods can result in lost gears and consequent ghost fishing – the ability of the gear to cause mortality after it has been lost. Lost nets have a high possibility of destructive ghost fishing ('FGE' project) and lost nets and traps can continue to fish for at least six months. To facilitate escape the use of biodegradable door clips in traps has been recommended, however, there is little that can be done to remedy the problem of lost nets.

Impacts on Fish Fauna

The impact of consecutive trawling has been looked at in catches from seasonal experimental trawling in the Pagasitikos Gulf in central Hellas. The 'FGE' project reported that in respect of fish communities, overall species number and abundance did not show great differences with repeated trawling. The catch composition changed with indications of early removal of gadoids (predominantly bentho-pelagic schooling species) and territorial species or those with smaller mobility ranges (e.g. flatfish) and increases over time in more opportunistic scavenging species that obviously take advantage of damaged fauna or turned over sediments.

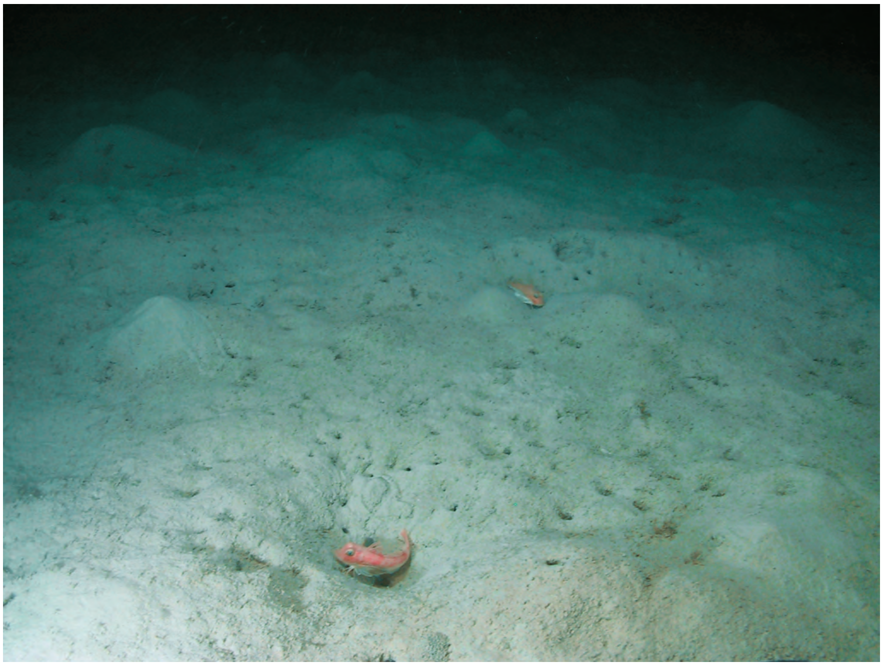


Figure VIII.25:
Normally bioturbated sediment in an untrawled area approximately 1 km from the Figure VIII.24 image.

Impacts on Sea Bed Fauna

Several, small to medium temporal and spatial scale, studies on the sea bed fauna (megafauna, macrofauna and meiofauna) have indicated that trawling impacts can be evident at both the community and species-groups level. The 'FGE' project (SMITH *et al.* 2000) investigating the megafauna on a deep (approx. 200 m) commercial trawling ground in the southern Aegean, found that some species particularly the large non-mobile filter feeding epibenthic species, such as soft corals, ascidians and crinoids are adversely effected. Conversely mobile scavenging species, particularly crustaceans were more prevalent in trawled areas in soft sedimentary areas. The 'OTIP' project (COGGAN *et al.*, 2001) by comparing trawled and untrawled sites in both deep muddy and shallow maerl grounds, found differences in functional groups and species richness of megafaunal communities. The 'FGE' project reported lower macrofaunal species number, abundance and biomass in a commercial trawl area compared to adjacent non-trawled areas of similar depth (200 m) and sediment type (fine muds). The 'TRIBE' project (SIMBOURA *et al.*, 1998) investigating shallower (60-70 m) trawled and untrawled areas, reported increased species number and abundance in the trawled areas, which were primarily due to sediment type differences (higher values in the coarser 'mixed' sediments of the trawled area). However, a shift in macrobenthic community structure seen, in the form of an increase in the number of polychaetes and opportunistic macrofaunal groups (often a sign of environmental disturbance linked to eutrophication) was attributed to trawling activities. The 'INTERPOL' project compared commercially trawled areas over time (during the open and closed season for trawling) reported no meiofaunal abundance response to trawling disturbance but analyses of effects on diversity and size distribution are pending. The 'TRBIOGEO' project indicated disturbance of the hyperbenthic community in such a degree that it probably increases the vulnerability of these animals to their predators. Data on recovery dynamics are still largely missing, but evidence suggests that long-term changes are probably restricted to long-lived fragile species or communities that are infrequently disturbed by natural phenomena.

Impacts on Seabed Processes

The effect of trawling on sedimentary processes will strongly depend on the type of sediment impacted. The 'OTIP' project (SMITH *et al.*, 2003) using sediment profile imagery, showed that in coarse sediments trawling impacts are seen as flattening and sweeping across the sediment. In softer sediments, however, a trawl will have greater penetration with more consequences to sedimentary processes. Normal chemical gradients are disrupted and the fauna can be strongly affected, which in turn has a strong structuring effect on biogeochemical processes. The 'FGE' project has attributed differences in the sedimentary chemical parameters (organic carbon and chlorophyllous pigments) to trawling impacts; these could either be due to greater mixing of sediments or from impacts on the biogeochemical processes that act on these parameters. 'INTERPOL' and 'TRBIOGEO' reported elevated nutrient concentrations during trawling. Studies are underway or have yet to be fully reported on investigations into the impact of trawling on nutrient and oxygen fluxes and bioturbation. 'COST-IMPACT' is one such study, where seasonal experiments have shown that there were significantly higher fluxes of oxygen in the water in the trawling ground during summer (C. SMITH, unpublished data).

Endangered Species and Habitats

Accidental capture in gill nets is thought to be the main cause of population decline of some endangered species such as the monk seal *Monachus monachus* and the loggerhead turtle *Caretta caretta*. Small dolphin species are infrequently caught by gill nets and on rare occasions, turtles and sharks are caught by long lines. During the last decade, however, protection of the monk seal habitat has been ensured by the establishment of the Sporades Marine Park, while cetaceans and marine turtles in the Mediterranean are legally protected under the Action Plan for the Conservation of Cetaceans. Overexploitation has led to a serious decline of the red coral *Corallium rubrum* and many other invertebrates. The *Posidonia oceanica* meadows in Hellas are partially or fully protected from trawling depending on regulations (trawling is forbidden less than 3 miles from shore or in depths less than 50 metres) but there are indications on partial degradation of this habitat in 'NATURA 2000' sites (see Chapter Benthic macrophytes VI.2).

CONCLUSIONS

There is no doubt that fishing has an impact on the Hellenic environment. Many components are impacted (both negatively leading to a loss of biodiversity and positively with some increases in sea bed biomass reported) with the environment no longer being a 'natural' environment. The area that is affected is a very small percentage of the total Hellenic waters, but it is the most important part in terms of usage and resources. Our scientific knowledge of the ecosystem and the detailed quantifiable impacts of trawling are still less than sufficient to give precise numbers, to be used for management purposes. We should, therefore, use the precautionary approach to the management of impacts on habitats and non-target species and develop new fisheries in a gradual manner, scaled to the knowledge available. Several tactics exist whereby management uncertainty can be reduced and one of the most important of these is the creation of no-take zones or marine reserves (creation of temporary and permanent marine reserves). Given the management situation in the Mediterranean, such approaches have the greatest chance of being effective.

VIII.5. FISHERIES IMPACT ON TROPHIC LEVELS: LONG-TERM TRENDS IN HELLENIC WATERS

Overfishing, that is the removal of marine organisms at a rate much faster than that supported by the ecosystems in which these organisms are embedded, has been documented for both coastal and open-sea ecosystems by many research groups (e.g. PAULY *et al.*, 2002, MYERS & WORM, 2003, CHRISTENSEN *et al.,* 2003). Overfishing dramatically impacts all levels of biological organisation of marine life: populations, communities and ecosystems.

Among the various effects of overfishing, those related to the trophic structure and thus the energy flow within marine ecosystems have received particular attention in recent years because of the pioneering work of Pauly and his co-workers from the Fisheries Centre of the University of British Columbia (Canada). This group used the fisheries catch statistics published annually by the U.N. Food and Agriculture Organisation (FAO) and the trophic level (for its definition/estimation, see Box 1 in Chapter VII.2), of all species or groups of species participating in the catches. They showed that the mean trophic level of the catches declined by about 0.5-1 trophic level during the last 50 years (PAULY *et al.*, 1998). Such a decline was generally true both on a global scale (i.e., when considering the global marine catches) and on an ocean-specific scale (i.e., for each of the different FAO subareas of the Atlantic, Indian and Pacific Oceans, and the Mediterranean-Black Seas). For the definition of trophic level readers are addressed to Chapter VII.2 in this volume.

Ecologically, this decline in mean trophic level can be explained based on the relationships between fishing, sizes of organisms fished and their trophic levels. In general, fishing selectively removes the largest organisms and this is true of both between- and within-species. Since trophic levels in marine organisms generally increase with size, again both between- and within-species, intense fishing lowers the relative catch contribution of large-sized organisms, positioned high in the food web. As a result, fisheries catches are progressively dominated by small-sized fishes (i.e., the mean trophic level of the catches declines with time).

The approach of Pauly's group had an important impact on fisheries science and became known as the **'fishing down the marine food web'** process. Although CADDY and his co-workers (1998) raised various sources of bias that might have affected the results of Pauly's group, all of these concerns were later fully addressed (for a detailed account see: PAULY & PALOMARES, 2005). Furthermore, 'fishing down' has been also verified by other scientists on smaller, regional scales (e.g. North Sea, Celtic Sea, Icelandic waters, Canadian waters, Cuban waters and the Mediterranean Sea; PAULY & PALOMARES 2005).

For the Hellenic Seas, a preliminary analysis (CIESM, 2000) showed that in many areas of the Aegean Sea (i.e., the Saronikos Gulf, the Thermaikos Gulf, the Sea of Thraki and the southern Aegean) the mean trophic level of the catches decreased during recent years. In contrast, 'fishing down' was less pronounced in the Hellenic part of the Ionian Sea. This preliminary analysis was based on the catches of fish, cephalopods and crustaceans, reported by the National Statistical Service of Hellas for 1964-1997 and preliminary gross estimates of the trophic levels of the species making up these catches. In this report, the catch time-series is extended back to 1950, using the FAO data and restricted to fish species only.

DATA AND METHODS USED

The Hellenic catches of all fish species (or group of species, henceforth called species) from the FAO fishing subarea Mediterranean-Black Sea (FAO subarea 37) during 1950-2001 were extracted from the FAO global fisheries capture database using the software Fishstat Plus (version 2.30; both catches and software downloadable from www.fao.org). Firstly, Hellenic fish catches were aggregated by four trophic level classes, i.e., 2-3, 3-3.5, 3.5-4 and 4-4.5, and plotted against time. Secondly, the mean trophic level of the catches of all fish and of fish with trophic levels higher than 3.5 and 3.75, and the corresponding 'Fisheries in Balance' (FiB) indices were also computed and plotted against time.

All someone needs to estimate the mean trophic level of the catches derived from a marine region are the individual catch weight and trophic level values of all species participating in the local catches. In this case, the mean trophic level of the catch in a particular year is estimated by multiplying the trophic level of each species by its catch weight; add these across all species participating in the catches and divide this by the total catch of all species in this particular year (PAULY *et al.*, 1998).

The FiB index is used to track the 'fishing down the food web' process (PAULY & PALOMARES, 2005). Given a time-series of catches and their mean trophic levels, the FiB index is calculated for each year of a time-series, as the ratio, at a log scale, between: (a) the total annual catch, multiplied by the energy transfer efficiency between trophic levels (an ecosystem property, having a mean value of 10%) after the latter has been raised to the mean trophic level of the catch and (b) the estimate of (a) above for the first year of a time-series as a reference (PAULY & PALOMARES, 2005). The FiB index (PAULY & PALOMARES, 2005): (a) attains a value of 0 for the first year of the series; (b) does not vary during periods in which trophic level and catches change in opposite directions; and (c) increasing or decreasing FiB values indicate a geographic expansion or contraction (or collapse) of the underlying fishery, respectively.

The mean trophic levels of the catches and the FiB index for 1950-2001 were estimated using the trophic level values from STERGIOU & KARPOUZI (2002) supplemented, when necessary, with trophic level values from FishBase (www.fishbase.org).

CHANGE IN TROPHIC LEVEL OF CATCHES

Fish Catches per Trophic Level Class

Fish with trophic levels ranging between 3 and 3.5 dominated the catches by far, contributing 62% to the mean total catch during 1950-2001. They were mainly represented by the small pelagics anchovy and sardine, followed by the Mediterranean horse mackerel, picarels, chub mackerel, red mullet and pandora. The total catches of fish with trophic levels from 3.5 to 4 contributed 18% to the mean total and were mainly composed of blue whiting, Atlantic mackerel, Atlantic horse mackerel, rays, scorpionfish and other species groups. Finally, the species groups with the lowest and highest trophic levels (i.e., 2-3 and 4-4.5, respectively) each contributed about 10 % to the mean total. The catches of the first group (2-3) were composed of three species only, bogue, salema and mullets, whereas those of the second group were dominated by large demersal fish, such as hake and groupers, and large pelagic fish, such as bonito, swordfish and tunas.

The catches of these four groups rapidly increased from the early 1950s to a peak in 1994 followed by a decline (Figure VIII.26). The ratio between the maximum and minimum catch during 1950-2001 was higher for the 3.5-4 trophic level group (=11) when compared with the remaining ones (9, 4 and 8 for trophic level groups 2-3, 3-3.5 and greater than 4, respectively).

'Fishing down' and the FiB index

Figure VIII.27 shows the mean trophic level of the total catches during 1950-2001, from which it becomes evident that it smoothly declined by 0.1 trophic level during 1950-1980 and increased again during the years following 1980. The increase in the second period clearly resulted from the fact that the increase in the catches of fishes having trophic levels 3.5-4 and, to a lesser extent, 4-4.5, more than compensated for the increase in the catches of the lower trophic level fish (Figure VIII.26). Indeed, the picture changes when one considers only high trophic level fish; in this case a declining trend with time becomes apparent during 1950-2001, being steeper in the case of trophic levels greater than 4 (Figure VIII.27).

Figure VIII.28 shows the variations in the FiB index during 1950-2001. For all fish species, FiB fluctuated around zero during the period from 1950 to the early 1970s, followed by a linear increase to a peak in 1994 and a decline thereafter. This was also the case for fish with trophic levels greater than 3.5 (Figure VIII.28). The increase in the FiB index indicates a general 'expansion' of the Hellenic fisheries, which indeed has taken place

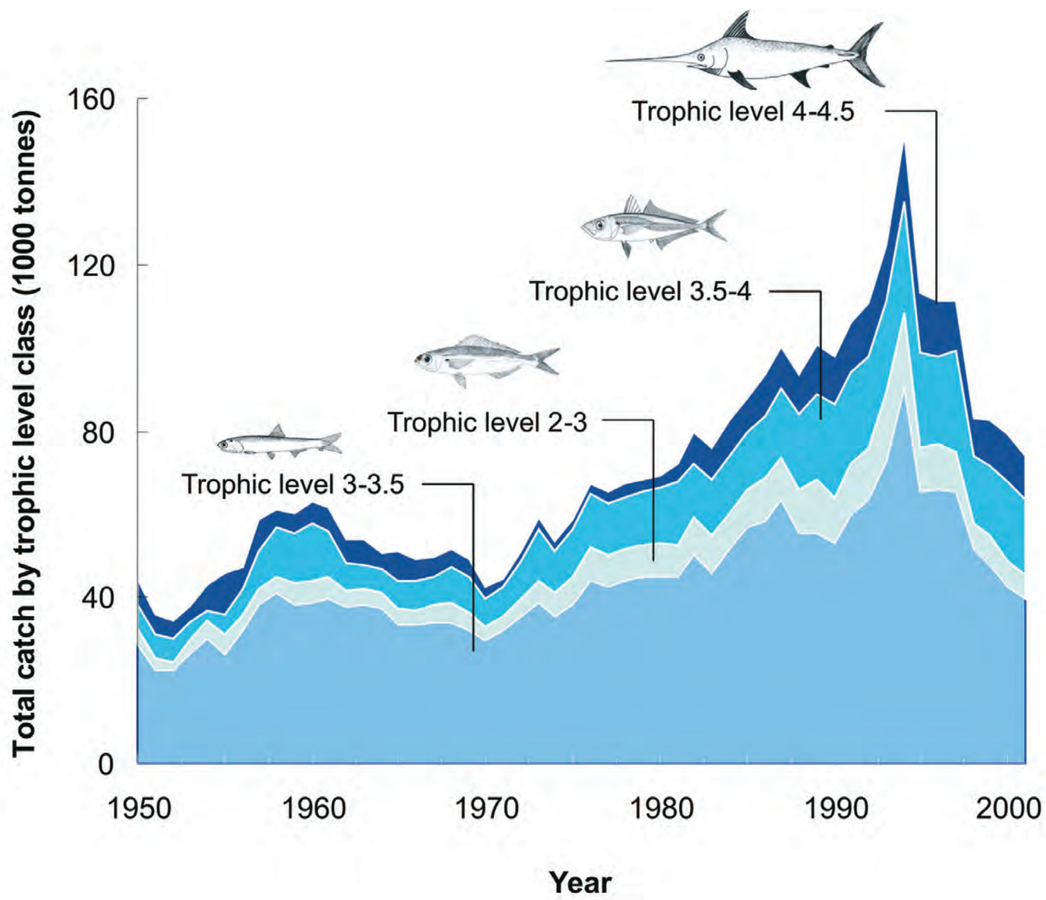


Figure VIII.26: *Hellenic waters, 1950-2001. Long-term changes in fish catches aggregated by four trophic level classes.*

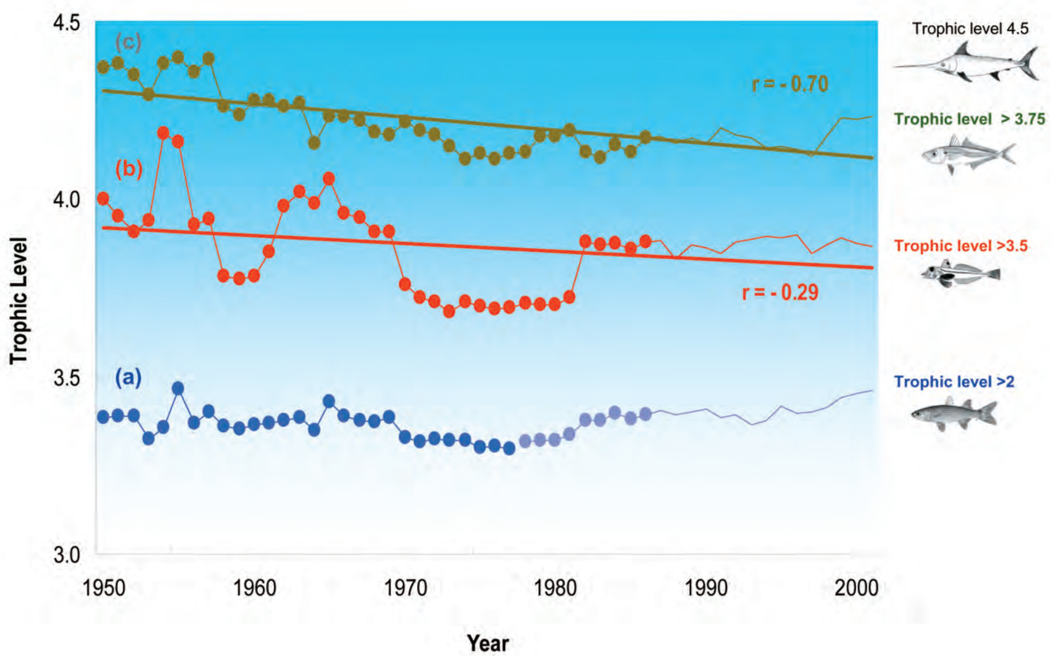


Figure VIII. 27: *Hellenic waters, 1950-2001. Long-term trends in the mean trophic level of catches for all fish species (trophic levels >2) and for fish species having trophic levels >3.5 and >3.75.*

during the 1980s and early 1990s for two reasons; the modernisation of the fleet and the effect of man-made eutrophication on the productivity of coastal waters.

The modernisation of small- and large-scale fishing fleets (i.e., larger boats, of higher tonnage and engine horsepower, improved fishing gears, use of high-technology equipment; STERGIOU *et al.*, 1997) led to the expansion of fishing in open-sea areas, previously largely inaccessible by fishing vessels because of strong winds (e.g., in southern waters) and in deep water areas. As a result, new 'resources' started to be exploited, mostly at high trophic levels (i.e., greater than 3.5). These new resources refer to both species not previously exploited as well as to the large, mature individuals of many previously-exploited species (e.g., hake), which by inhabiting deep waters were inaccessible by trawlers (i.e., deep water areas acted as natural 'no-take' zones).

In addition, the general increase in man-made eutrophication of Hellenic and Mediterranean waters during the last decades (e.g. CADDY *et al.,* 1998) boosted productivity in coastal waters. This increased fisheries catches across all trophic levels and further contributed to the 'expansion' of the Hellenic fisheries.

Thus, fish from areas previously not exploited and fish 'generated' by eutrophication formed the basis of the Hellenic fisheries during 1980-1995, replacing the fish which 'fishing down' has removed. The use of the FiB index revealed this effect. However, the misleadingly good consequences of technology and eutrophication have faded away, judging from the recent, downhill catches across all trophic levels (Figure VIII. 26).

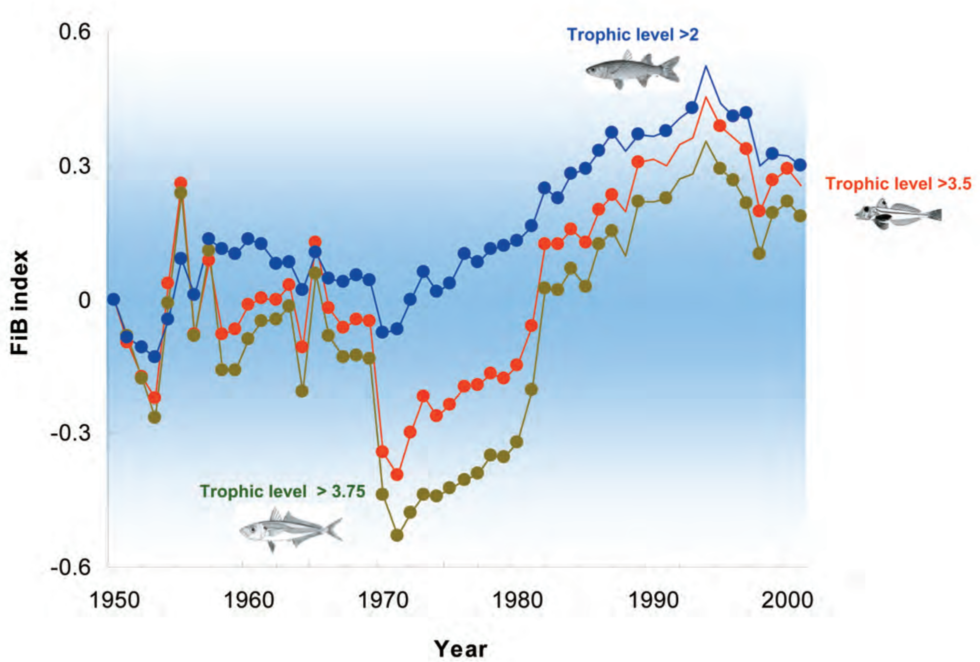


Figure VIII.28: *Hellenic waters, 1950-2001. Long-term trends in the FIB index of the catches of all fish species (trophic levels >2) and of fish species having trophic levels >3.5 and >3.75.*

VIII.6. ENVIRONMENTAL IMPACTS OF FISH FARMING

Aquaculture and particularly fish farming have expanded almost exponentially during the last two decades in Hellas. The low labour cost, the financial support by the EU and the Hellenic State during the early years of aquaculture, as well as the efficient transferring of the technology needed, have made this industry an example of rapid and successful growth of aquaculture. However, besides these economic aspects, fish farming has benefited by some key-characteristics of the marine environment, which contributed even more to this 'story of success':

- The high water temperature in the Mediterranean allows faster growth of the farmed species and extends the production period to cover all seasons of the year.
- The clear oligotrophic waters of the Mediterranean and particularly in the eastern basin provide an ideal background in water quality ensuring minimal stress on the farmed species.
- The extended coastline of Hellas (accounting ca 1/3 of the total EU coastline) provides many sites completely unaffected by human disturbance or pollution, some of which have been used for fish farming.

The expansion of aquaculture in Europe has faced reactions at either local or national levels. Hellas is no exception to that. Concerns have been expressed by the tourist industry claiming both developed and pristine beaches for further development, local fishermen claiming traditional coastal fishing grounds, by people using remote areas for summer housing or recreation and by environmentalists generally opposed to the private use of coastal waters.

During the last decade there has been considerable effort invested in research on environmental impacts of fish farming. Both national and EU funded projects have addressed complementary aspects of this issue in a variety of different conditions and sites, resulting in substantial gain in the understanding of the relevant processes. Hellenic and other European scientists have sampled more than 15 farming sites in Hellenic coastal waters, using state-of-the-art equipment, a wide spectrum of methods and techniques, and investigating a series of scientific hypotheses related to the impact of wastes on coastal ecosystems. Results of these studies have been published in international journals, presented in international symposia, but also disseminated to the interested parties such as regulators, local authorities, fish farmers' associations, environmental consultants and NGOs to increase the use of scientific information in the context of a rational planning of coastal activities.

Highlights of the most significant findings are given below.

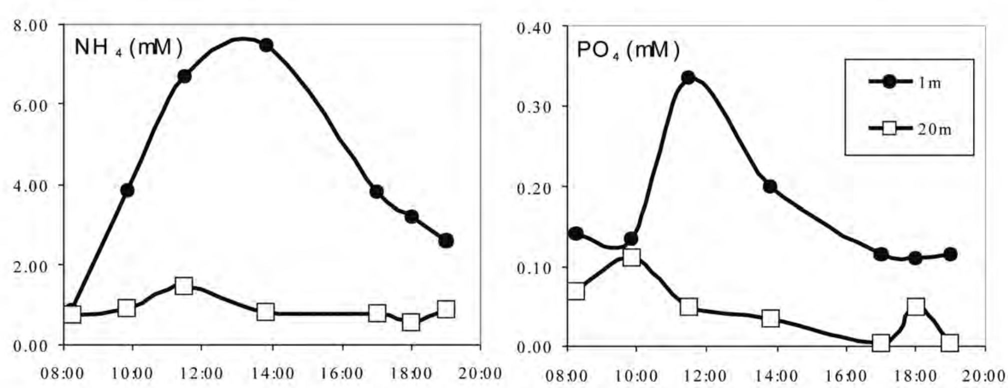
EFFECTS ON GEOCHEMICAL CHARACTERISTICS OF THE COASTAL ENVIRONMENT

The effects of fish farm wastes on marine geochemistry have been investigated in the framework of the AQUAENV project (funded by the Hellenic General Secretariat for Research & Technology). It has been shown that dissolved wastes (primarily ammonium and phosphate) have little impact on nutrient loading at the farming sites, not exceeding other sources of variability and particularly they had no significant effect on chlorophyll-a or particulate organic carbon in the water column, both of which when in excess, could be regarded as signs of eutrophication (PITTA *et al.*, 1999). Furthermore, it has been shown that due to dispersive characteristics of the farming sites, any increase in nutrients is rather restricted in time following a diel pattern (KARAKASSIS *et al.*, 2001) (Figure VIII. 29). In this context, it is not surprising that there has been little evidence in the scientific literature on effects of fish farming on water quality (BEVERIDGE, 1996).

The effects of particulate wastes are more readily detectable. It has been shown that the accumulation of unused food and faecal pellets results in conspicuous changes to the physical and chemical properties of the marine sediments beneath the cages (BELIAS *et al.*, 2003). The sediment in this zone is often anoxic, with high carbon content and rich in phytopigments. However, it is worth noting that there are significant changes depending on the depth, the size of the farm and the texture of the bottom sediment: coarse sediments under strong currents and deep sites tend to have substantially lower accumulation of particulate wastes. Furthermore, it has been shown that the sea bed zone affected does not exceed a distance of 10-25 m from the edge of the cages (Figure VIII.30). A recent investigation of sedimentary geochemical variables at larger spatial scales in areas surrounding fish farming zones (AQCESS project), showed no significant changes (not even subtle ones) at a distance of 1-10 km.

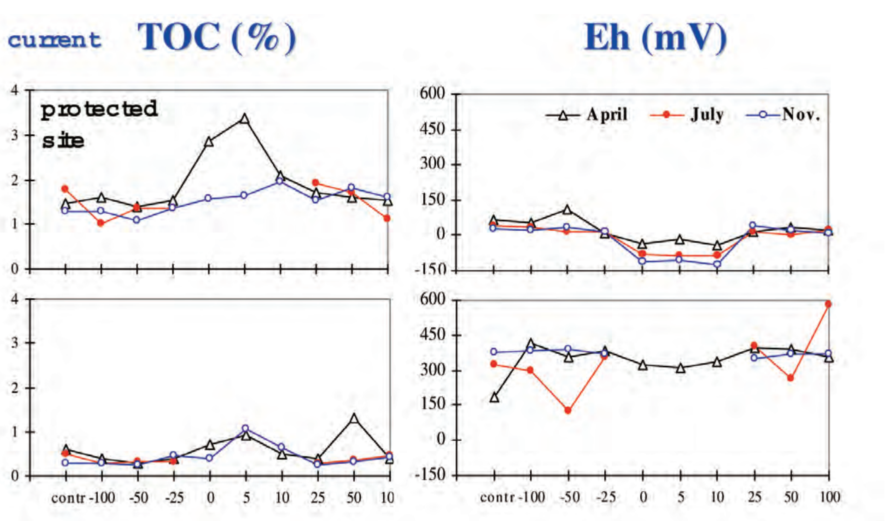
Recent results of the MERAMED project (*Development of monitoring guidelines and modelling tools for environmental effects from Mediterranean aquaculture*) have confirmed the above results in seven more sites in Hellenic coastal waters, resulting in an operational modelling tool (MERAMOD) accommodating site-specific peculiarities and production levels, by adapting a tool previously developed for Scottish sea loch environments (CROMEY *et al.*, 2000) to Mediterranean conditions.

Finally, it should also be noted that even in the



Source: *data from KARAKASSIS et al., 2001.*

Figure VIII. 29: *Diel changes in nutrient concentrations in the water column within a fish farm.*



Source: *data from KARAKASSIS et al., 2000.*

Figure VIII.30: *Changes in sediment geochemistry (total organic carbon and Redox potential) with distance (in m downstream) from fish farms.*

worst case (shallow, silty sites) the signs of degradation of the sediment beneath the farms are subject to significant seasonal changes, becoming less severe during winter when the food supply decreases and sediment resuspension and oxygenation increase.

EFFECTS ON PLANKTON

Results from the aforementioned AQUAENV project (PITTA *et al.*, 1999) have shown that plankton assemblages near the fish farms are not significantly different to those at the control sites, in terms of either quantity (abundance) or quality (diversity, species composition). Furthermore, recent experiments in the framework of the MedVeg project (Effects of nutrient release from Mediterranean fish farms on benthic vegetation in the coastal ecosystem) have shown that there is a pronounced effect of microplankton grazing on phytoplankton cells, which prevents the bloom of phytoplankton despite the constant supply of nutrients by the fish farms.

Despite the relatively low effects on nutrients and phytoplankton found so far in Hellenic coastal waters as well as in other European coastal ecosystems, an EU project was carried out to provide mitigation alternatives to the fish farming industry. The BIOFAQs project (Biofiltration and Aquaculture: an evaluation of hard substrate deployment performance within Mariculture developments) was designed to test the efficiency of biofilters (Figure VII.31) as a means of reducing in situ the discharge of nutrients into the sea and thus to avoid even subtle environmental changes that could disturb other uses of the coastal zone.

EFFECTS ON BENTHIC ANIMALS

The effects of settling particulate material on benthic organisms investigated in the framework of the AQUAENV project showed significant changes in benthic communities beneath fish farms. Although none of the sites investigated were grossly polluted (i.e. azoic), there was a considerable decrease in benthic diversity, since the seabed was mainly inhabited by small sized opportunistic species. However, again in this case, the area affected was less than 25 m from the edge of the cages (Figure VIII.32). Macrobenthic organisms are globally and traditionally used as a means for assessing environmental degradation caused by a variety of anthropogenic activities. The AQUAENV studies (KARAKASSIS & HATZIYANNI, 1999) and more recently, the results of the MERAMED project have shown ways to minimise costs during the monitoring of fish farming effects while maintaining the reliability of the results.

Figure VIII 31:
Sampling biofilters deployed in the vicinity of a fish farm.

Source: *copyright IMBC.*

Furthermore, the MERAMED results have shown there is a correlation between the predictions of the MERAMOD model on sedimentation rates and the condition of the benthic communities.

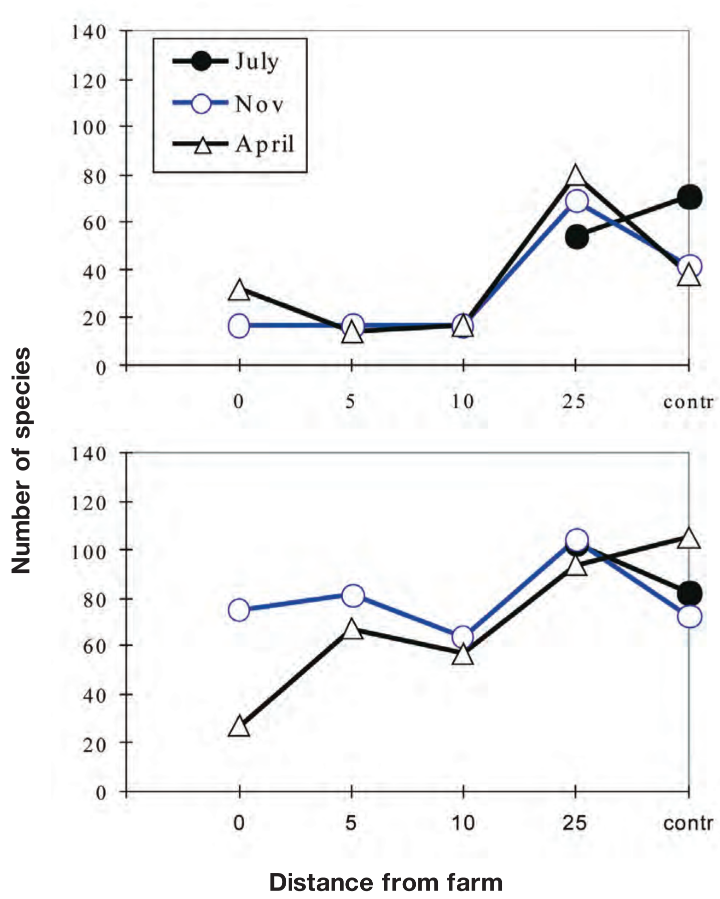
In a paper reporting data from two sites in Hellenic coastal waters, PAPOUTSOGLOU *et al.*, (1996) reported that visual inspection by divers failed to detect any effects on the sea bed under the fish cages. Similar results were reported from a survey using an acoustic ground discrimination system carried out in Selonda Bay by MCDOUGALL & BLACK (1999).

Recent investigation of changes at larger spatial scales in the framework of the AQCESS project showed that there was little change in community structure or feeding types of the macrobenthic organisms. However, there was an increase in the biomass of megabenthos at a distance of 1-10 km which could be associated with the presence of fish farming zones.

The degradation of marine benthic communities after 10 years of farming in a particular site is probably reversible, although the time needed for the complete recovery after the cessation of fish farming in that site is more than two years (KARAKASSIS *et al.*, 1999).

EFFECTS ON WILD FISH

The effects on wild fish have been recently investigated in the framework of EU-funded AQCESS project (Aquaculture and Coastal, Economic and Social Sustainability). This survey involved experimental trawling (3 areas by 2 seasons) at near and far fields, before-after



Source: *Data from KARAKASSIS et al., 2000.*

Figure VIII.32:
Changes in number of species of benthic invertebrates in the immediate vicinity of fish farms and a control station (a) at a protected site and (b) at an exposed site.

comparisons of catches, hydroacoustic surveys over large spatial scales, underwater investigations by means of ROV (Remotely Operated Vehicle) and time-series analysis of commercial data on fish landings in five different areas (with and without fish farming effects). The results of this project have shown clearly that the presence of aquaculture zones induces higher abundance, biomass (by a factor of two) as well as higher diversity at intermediate spatial scales (1-20 km) which positively affects local fisheries by increasing total landings. This effect is probably related to the oligotrophic regime of the Aegean Sea, where even small amounts of nutrients are rapidly and effectively transferred up the food chain. It is worth noting that in the framework of AQCESS, an identical survey conducted in parallel in the more productive waters of north Atlantic showed little response of wild fish abundance and biomass to the presence of fish farming zones.

EFFECTS ON BIODIVERSITY

Although some species are directly affected by aquaculture and species diversity beneath cages is generally decreased, it is not certain that the biodiversity is in danger due to fish farming. According to MARGALEF (1997), there is a clear distinction between biodiversity (i.e. the total number of available species or genotypes in an area) and ecological diversity or eco-diversity which can be inferred by sampling local biotic communities. In this context, the local changes in community structure, affecting a few square metres cannot be considered as a decline in biodiversity. By contrast, risks for biodiversity arise when a particular type of habitat (rare, endemic or supporting an endangered species or a key-habitat supporting life of the wider area) is severely degraded over a large scale or when populations of k-selection species (i.e. those of large size and low reproduction rates) are reduced to unsustainable sizes. At present most of the scientifically documented effects are those on macrofaunal invertebrates at a zone beneath and close to the farm cages. These organisms are ecologically important but it is very unlikely that they will become extinct or that their populations at larger spatial scales will be significantly affected.

The potential problems affecting biodiversity in relation to aquaculture are the mortality of large fauna, the effects on sea-grass meadows and the changes in the trophic status of large water bodies.

As discussed above there is little evidence of change in trophic status from fish farming zones in Hellenic coastal waters, where all the sites investigated have been found to maintain their oligotrophic characteristics. Although not specifically addressed in any known local project, there is also little evidence that large k-selection animals have suffered losses due to their interactions with fish farming or fish farmers. However, the effects on sea-grass meadows and particularly Posidonia oceanica are probably a risk to biodiversity since the habitat of this phanerogam is ideal for fish farming (strong currents, coarse sediment, adequate oxygenation and clear waters). In this context, the MEDVEG project has investigated the effects in Hellenic coastal waters as well as in three other Mediterranean countries along an east-west transection. The work is still in progress but there are considerable indications that fish farming has a significant negative effect on the Posidonia meadows and, therefore, it could pose an important risk if sites are not properly selected (HOLMER *et al.*, 2003).

COMPARISONS WITH OTHER MARINE AREAS IN THE WORLD

In comparison to other coastal marine areas, the sites used for fish farming have shown similarities and differences depending on the specific attributes examined:

- Regarding the effects on the water column and plankton communities there is little published information providing evidence for eutrophication with the exception of the eastern Baltic. The oligotrophic conditions prevailing in Hellenic Seas, even close to the coast, are unlikely to change due to this specific activity.
- The benthic effects are highly localised as also found in many other areas of the world as well as in the Mediterranean. However, the level of change seemed to be lower than that observed in some of the published papers which reported extensive sediment anoxia, large patches of *Beggiatoa* and absence of macrofauna in relation to salmon farming in the North Atlantic and the Baltic Sea. MCDOUGALL & BLACK (1999) reporting data from the Mediterranean have attributed the relatively low impacts of organic enrichment

on the sea bed to the consumption of the organic material by demersal fish and invertebrates which was confirmed during recent surveys of the MERAMED project.

- The effects on wild fish and on fisheries seemed to be positive, i.e. there was an increase in biomass and landings with no adverse effect on diversity of the fish communities. There are no published data addressing this issue anywhere else. However, unpublished data from the AQCESS project indicate that this is probably an exceptional effect related to the oligotrophic regime in the Mediterranean.
- The effects on the *Posidonia* meadows are probably the most alarming and need to be addressed thoroughly both in terms of science and in terms of regulatory action.

VIII.7. CHANGES IN SPECIES: INVASION OF EXOTIC SPECIES

What are exotic species?

The term exotic, alien, introduced, invasive or non-indigenous species is used to define a species that enters an aquatic ecosystem outside its historic or native range.

Invasions of exotic marine animals and plants into coastal waters are not new. For centuries wooden ships transported innumerable species both in them (as boring organisms) and on them (as fouling communities). In the last quarter of the 19th century, commercial oysters began to travel or be transported around the world in huge numbers carrying with them an untold number of epizoic and endozoic species, as well as entire estuarine communities in the mud and seaweed packed with these oysters.

How do they arrive?

The present high number of invaders in the eastern Mediterranean is to be attributed, apart from natural introductions, to fortuitous events, shipping and/or intentional introduction. Historically, wooden sailing ships provided an ideal surface to which marine fouling organisms could attach, leading to biological invasions throughout the world over centuries and to the biological homogenisation of the world's oceans. Until recently, such transport was limited mainly to animals that attached themselves to or burrowed into the hulls of ocean-going vessels. The main pathways of species' introduction in the Mediterranean Sea can be summarised as follows:

a) Natural introduction through Channels (Straits of Gibraltar, Bosphorus Straits);

b) Human-mediated introduction, including:

- the Suez Canal opening-up;
- ballast waters, fouling and clinging of ship hulls, drilling platforms etc.;
- accidental invasions, such as escapees from aquaria, research institutions, aquarium trade etc.;
- discards of live imported specimens back to the sea (baits, fauna associated with algae used as packing material etc.);
- aquaculture, with intentional introduction of species for commercial exploitation and/or accidental introduction of accompanying species.

The vast majority of invasions are believed to be due to human-mediated activities. While, for the western Mediterranean, aquaculture is considered as the second important source after ballast-water conveyance, the opening of the Suez Canal is responsible for the greatest and best-documented invasion worldwide and is the major source of invasion for the Hellenic region. The opening of the Suez Canal in 1869 initiated the invasion of Erythrean biota into the Mediterranean Sea, known as Lessepsian migration. Ballast water from ships contains a variety of aquatic organisms. When ballast water is released into the environment, these organisms are introduced into the local ecosystem, where they compete with indigenous organisms for food and may clog up water intake pipes.

MEDITERRANEAN - HELLENIC EXPERIENCE

The incidence of invasive species

During the last two decades, the ctenophore *Mnemiopsis leidyi* invaded the Black, Azov, Marmara and Aegean Seas, and recently, the Caspian Sea. The *M. leidyi* invasion negatively affected the ecosystems of the Black Sea and the Sea of Azov, where the zooplankton, ichthyoplankton and zooplanktivorous fish stocks underwent profound changes. Similar effects, but less pronounced, were recorded in the Sea of Marmara, while effects on the Hellenic water's food chains remain so far, insignificant. Salinity is supraoptimal here and several predators probably prevent *M. leidyi* from reaching outbreak levels.

An invasive clone of aquarium origin, the green alga *Caulerpa taxifolia*, has been spreading rapidly throughout the Mediterranean Sea since 1984 (MEINESZ & HESSE, 1991). From the first 1 m² of this alga discovered in Monaco in 1984, the present day situation concerns over 10 000 ha, present in six Mediterranean countries (Croatia, France, Italy, Monaco, Spain and Tunisia). As the management of invasive species is vastly different in Mediterranean countries, the official 'wait and see' politics has led to an uncontrolled situation in the Mediterranean. Even though it has not yet been observed in Hellenic Seas, its rapid expansion along the Mediterranean coasts represents a visible risk. Healthy *Posidonia oceanica* meadows appear to be a natural barrier to *C. taxifolia* colonisation (OCCHIPINTI-AMBROGI & SAVINI, 2003) and preservation of this important ecosystem, fortunately still prosperous along Hellenic coasts, could be the key to prevent invasion.

Rapana venosa, native to the Sea of Japan, was accidentally introduced into the Black Sea in the 1950s and has since spread to the Aegean and Adriatic seas. It has been speculated that the planktonic larvae of the species have arrived through ballast water, but a more likely scenario is that egg masses may have been transported with the products of marine farming i.e. oysters or mussels. It was first recorded in the northern Aegean Sea near natural oyster and mussel banks in the bay of Thessaloniki (a major port in the north Aegean) in the 1990s and according to the local Fisheries and Aquaculture Associations, it has now become a considerable nuisance in the oyster and mussel beds in the area. Considering the potential transfer of the species on a global scale in ballast water and its risk to commercial bivalve fisheries, the Working Group on Introductions and Transfers of Marine Organisms (WGITMO) has recommended (1999) that ICES alert Member Countries to this invasive species.

Rate of introductions

The first coloniser recorded in Hellenic waters was the angiosperm *Halophila stipulacea* (in 1895), now well developed along Hellenic coasts from the Aegean to the Ionian Sea. Nearly 40 years later (1934) the first Lessepsian fish was recorded and in 1946 the first exotic (lessepsian) mollusc was reported in the Saronikos Gulf. Since then, both fish and molluscan Erythrean fauna are continuously increasing their number.

Since the first record, there was a low rate of introduction into Hellenic waters, which has significantly accelerated during the last two decades. (Figure VIII.33). It is even more impressive if we consider that within the last four years (2000-2004) the number of new records of exotic species has risen to 16, adding eight more species to those listed in the CIESM Atlases (www.ciesm.org/atlas) from the Hellenic Seas.

Pathways of introduction

Up to date, a total of 90 exotic species (Table VIII.5), mainly benthic, have been recorded in Hellenic waters, with diverse patterns of introduction. Further investigation is needed of two more species, a bryozoan and an amphipod, that are suspected to be exotics.

Figure VIII.34 shows the percentage of invasion pathways in Hellenic waters. The most important way appears to be the Suez Canal opening, while the second is the accidental conveyance via shipping. The gradual introduction from the western Mediterranean is also significant, while the introduction from the Black Sea and

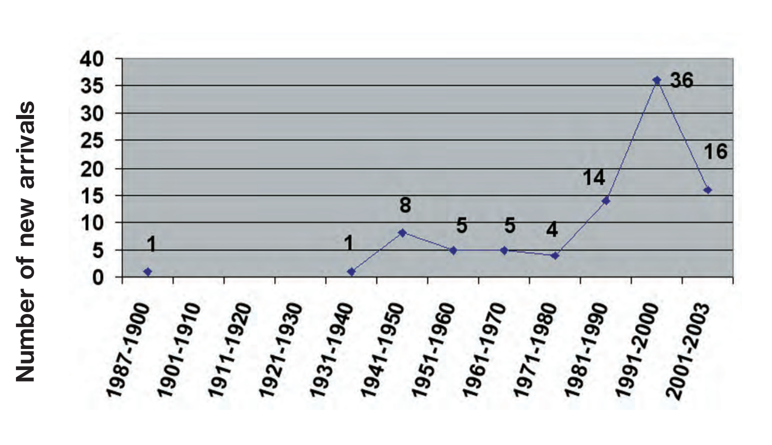


Figure VIII.33: *Rate of introduction of exotic species into Hellenic waters.*

Table VIII.5: *Mode of introduction and distribution of invasive species in Hellenic waters. LM=Lessepsian migration, S= Shipping, Oys.farm= Oyster farms, Unkn=uknown, Aquac = Aquaculture.*

	Mode of introduction		Mode of introduction		Mode of introduction		Mode of introduction
MOLLUSCA		*Trochus erythraeus*	LM	*Spirorbis marioni*	S?	**MACROPHYTA**	
Acteocina mucronata	LM?	**CRUSTACEA**		*Timarete anchylochaeta*	LM	*Acanthophora najdiformis* (Rhodophyta)	LM
Anadara demiri	S? Unkn	DECAPODA		**FISH**		*Asparagopsis armata* (Rhodophyta)	Gibraltar
Brachidontes pharaonis	LM	*Alpheus rapacida*	LM	*Alepes djedaba*	LM	*Codium fragile* (Chlorophyta)	Gibraltar
Bulla ampulla	LM ?	*Callinectes sapidus*	S	*Apogon pharaonis*	LM	*Colpomenia peregrina* (Chlorophyta)	Gibraltar
Bursatella leachi	LM	*Charybdis (Goniohellenus) longicollis*	LM	*Atherinomorus lacunosus*	LM	*Halophila stipulacea (Phaeophyta)*	LM
Cellana rota	LM	*Ixa monodi*	LM	*Callionymus filamentosus*	LM	*Sarconema scinaioides* (Rhodophyta)	LM
Crassostrea gigas	Oys farm	*Marsupenaeus japonicus*	LM	*Enchelycore anatina*	Via Gibraltar	*Stypopodium schimperi* (Phaeophyta)	LM
Crepidula fornicata	S? Unkn	*Metapenaeopsis aegyptia*	LM	*Fistularia commersoni*	LM		
Cylichna girardi	LM	*Metapenaeopsis mogiensis consobrina*	LM	*Gaidropsarus granti*	Via Gibraltar	**OTHERS**	
Fulvia fragilis	LM S?	*Portunus pelagicus*	LM	*Hemiramphus far*	LM	*Aspidosiphon (Akrikos) mexicanus* (Sipuncula)	Unkn
Gastrochaena cymbium	LM	*Thalamita poissonii*	LM	*Lagocephalus spadiceus*	LM	*Calanopia elliptica* (Copepoda)	LM
Haminoea cyanomarginata	LM?	*Trachysalambria palaestinensis*	LM	*Leiognathus klunzingeri*	LM	*Cassiopea andromeda* (Scyphozoa)	LM
Malvufundus regulus	LM	STOMATOPODA		*Mugil soiuy*	Via Marmara	*Centropages furcatus* Sea (Copepoda)	LM
Melibe fimbriata	LM?	*Erugosquilla massavensis*	LM	*Parexocoetus mento*	LM	*Hippopodina feegensis* (Bryozoa)	LM
Murex forskoehli	LM	**POLYCHAETA**	LM	*Pempheris vanicolensis*	LM	*Mnemiopsis leidyi* (Ctenophora)	Black Sea
Mya arenaria	S? Unkn	*Branchiosyllis exilis*	S	*Pteragogus pelycus*	LM	*Ophiactis savignyi* (Echinodermata)	LM
Nerita sanguinolenta	LM ?	*Cossura coasta*	LM	*Sargocentron rubrum*	LM	*Pseudocalanus elongates* (Copepoda)	Black Sea?
Petricola pholadiformis	S? Unkn.	*Hydroides elegans*	LM	*Saurida undosquamis*	LM		
Pinctada radiata	LM, Oys.farm	*Lysidice collaris*	LM	*Siganus luridus*	LM		
Pleurobranchus forskali	LM	*Metasychis gotoi*	LM	*Siganus rivulatus*	LM		
Polycerella emertoni	S	*Notomastus aberans*	Aquac	*Sphoeroides pachygaster*	Via Gibraltar		
Pseudochama corbieri	LM	*Paradyte cf. crinoidicola*	LM	*Sphyraena chrysotaenia*	LM		
Rapana rapiformis	LM ?	*Prionospio pulchra*	LM	*Sphyraena flavicauda*	LM		
Rapana venosa	S? Unkn.	*Prionospio salzi*	LM	*Stephanolepis diaspros*	LM		
Smaragdia souverbiana	LM ?	*Scoloplos chevalieri candiensis*	S?	*Upeneus moluccensis*	LM		
Strombus persicus	LM	*Spirobranchus tetraceros*	LM				

aquaculture contribution is very limited. Among 'invaders', 69 species (about 77 %) can be considered as true lessepsian migrants. Compared to the 17 species reported by POR (1978) in Hellenic waters about 100 years after the opening of the Suez Canal, a huge increase of Lessepsian species during the last two decades is noted.

Mollusc species are the most numerous invaders, followed by fish, polychaetes and decapods, as shown in Figure VIII. 35.

Distribution of Exotic Species in Hellas.

74 out of the total of 90 exotic species inhabiting Hellenic waters have been reported in the south Aegean Sea, 33 in the north Aegean and only 17 in the Ionian Sea (including the south Peloponnisos Gulfs). Another three species have to be added from the Libyan Sea (southeast of Kriti) and the northwest Levantine Sea, off the Rodos Gyre.

Detailed zoogeographical patterns of exotic species within the mentioned areas are shown in Figure VIII.36.

The majority of the exotic species (74) have been recorded in the south Aegean Sea while the number of species recorded in the rest of the Hellenic Seas decreases significantly northwards and westwards.

Within the south Aegean Sea, the Dodekanisos Islands are the most visited region by exotics, with a peak of 50 species, due to the influence of the Levantine Basin, the main occurrence area of exotic species within the Mediterranean.

The second area of expansion seems to be that of the Saronikos Gulf, on the route of many ships towards Peiraias, the biggest Hellenic port. The coastal area of the Cretan Sea, the Kyklades islands and the Evvoikos Gulf also host a significant number of exotics.

As far as the north Aegean is concerned, the bulk of exotic species can be detected in the northeast Aegean, mainly around the islands of Lesvos and Limnos, with a significant component of species

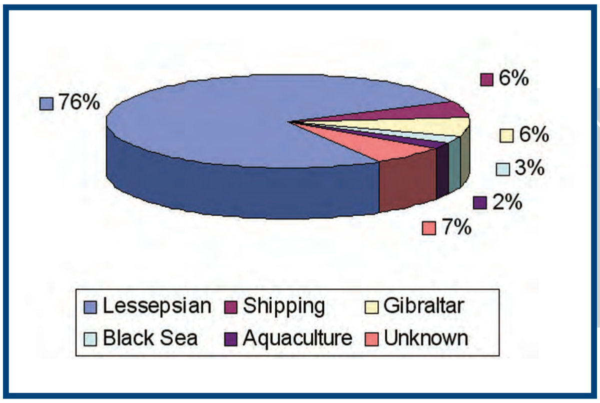


Figure VIII.34:
Pathways of introduction of exotic species into Hellenic waters.

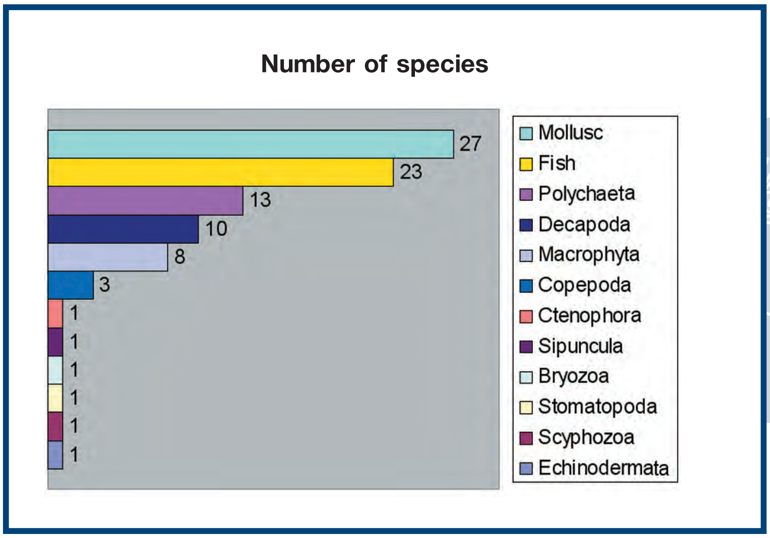


Figure VIII.35:
Number of invasive species per taxon in Hellenic waters.

coming from the Black Sea or introduced by shipping, following again the route of ships in areas where major ports are located.

Distribution of exotic species in the Ionian Sea and along the coasts of the Peloponnisos (Figure VIII.36) seems to be rather restricted (17 species) and only eight of them are definitely Lessepsian migrants. As for the remainder, three of them have been introduced by oyster farms, two by shipping, while the origin for the rest remains uncertain. The number of species recorded from the southeast Peloponnisos coasts and Gulfs is very small, probably due to two synergistic factors: lack of published information and avoidance or exclusion of the area from ships.

The Chronicle of Invasions in the Dodekanisos Islands

Based on the patterns of distribution presented here, it is inevitable that our attention focuses mainly on the Dodekanisos Islands, the closest to the coast of the Asia Minor Hellenic area. The Rodos Gyre, southeast of the island and the Asia Minor current (AMC) are the major hydrological features nearby. Significant changes in the south Aegean water mass characteristics have considerably influenced the thermohaline circulation of the eastern Mediterranean, termed the eastern Mediterranean climatic Transient (EMT) (For details see the chapter on hydrography). With regard to exotic biota of the area, 44 species (almost 90 %) are considered as Lessepsian migrants, four have been introduced via Gibraltar and two have been introduced by shipping (BOX 3).

With regard to the groups, exotic molluscs are not quite well represented in the area (seven species) and only three of them are Lessepsian immigrants. The finding of exotic molluscs mainly in harbours or neighbouring shallow waters leads

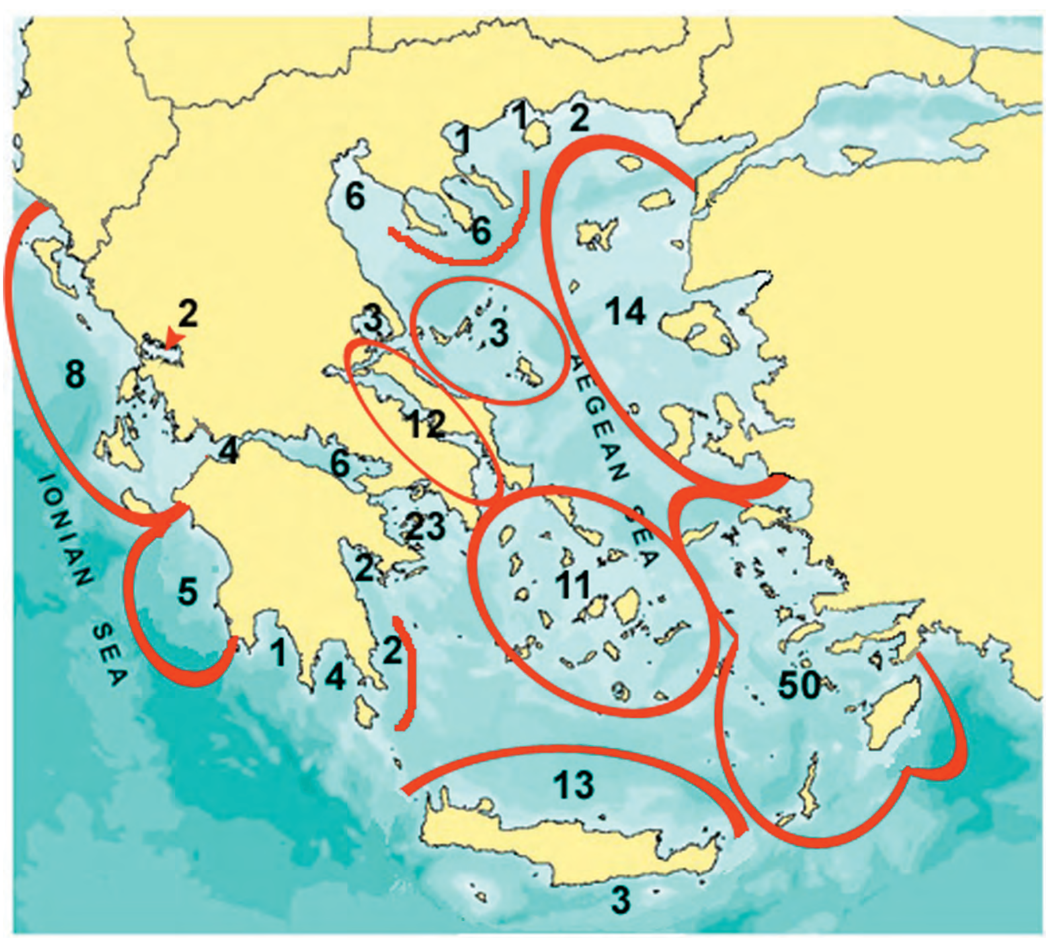


Figure VIII.36: *Number of exotic species recorded from the different Hellenic Gulfs and Seas.*

us to the conclusion that their larval stages are transported in ballast waters and follow only very slowly the pathway of lessepsian migration.

As far as fish fauna is concerned, after the first findings in 1960 and 1986, 11 more lessepsian migrants were recorded in the Dodekanisos area about 15 years ago (PAPACONSTANTINOU, 1990) and 23 exotic species (20 of them lessepsian migrants) are recorded in the present study. Furthermore, it is worth mentioning that eight species have been recorded during the last five years (1999-2003) and two of them (*Callionymus filamentosus* and *Sphyraena flavicaudata*) are reported herein for the first time in Hellenic waters (P. Mayers, pers. commun.).

Regarding Crustacea, a joint American-Israeli expedition performed in 1970 recorded no exotic decapods among the 29 species collected (LEWINSOHN, 1976). However, a recent study in Rodos recorded eight species (six decapods and one stomatopod of Indo-Pacific origin, and one decapod of Atlantic origin - KEVREKIDIS & GALIL, 2003), which together with the finding of a lessepsian portunid in the island (CORSINI *et al.*, 2003) affirms the range of extension of Indo-pacific crustaceans to the southeastern Aegean Sea.

The last decade was also decisive for the polychaetan fauna (six out of seven species recorded in the area).

The significant increase in the rate of introductions could be related to the sampling depth, as it is known that settlement of Erythrean species is favoured in shallow areas with warm waters. On the other hand, we cannot exclude the possibility of a gradual 'colonisation' of this 'hot-spot' region for biological invasions over time.

Conclusively, it seems that, apart from the increasing interest of the scientific community in the phenomenon, a gradual warming of the area is occurring over the last years, resulting in more

Box 3: *Chronicle of bioinvasions in Dodekanisos*

1894:	The sea grass *Halophila stipulacea* was found in Rodos harbour. (FRITSCH, 1895).
1957-1969:	Four new exotic species were recorded in the Dodekanisos Islands. (HUVE, 1957; BINI, 1960; KINZELBACH, 1970; NORDSIECK, 1969).
1970-1973:	Two more were added to the exotic fauna of the area. (BEN-ELIAHU, 1972; NORDSIECK, 1973).
1983-1984:	A study of the benthic macrofauna off northwest Rhodes recorded only three lessepsian polychaetes. (PANCUCCI-PAPADOPOULOU *et al.*, 1999).
1986-1989:	Three molluscs and one fish of Indo-Pacific origin were found in the area. (NICOLAY, 1986; QUIGNARD AND PRAS, 1986; TENEKIDES, 1989; BARASH and DANIN (1988/89).
1990:	Eleven fish species enriched the list of exotic species in the area. (PAPACONSTANTINOU, 1990).
1994-1999:	The exotic fauna and flora of the area were largely enriched, adding 13 new species (4 fish, 1 mollusc, 1 echinoderm, 1 phytobenthic species, 2 polychaetes and 4 crustacean) from various expeditions in the area. (BUZZURRO & GREPPI, 1994; ZACHARIOU-MAMALINGA & CORSINI, 1994; IUCN, 1994; KEVREKIDIS & KEVREKIDIS, 1996; PANCUCCI-PAPADOPOULOU, 1996; SIMBOURA, 1996; KEVREKIDIS *et al.*, 1998; ZACHARIOU-MAMALINGA, 1999; CORSINI & ECONOMIDIS, 1999).
2001-2003:	Nine more exotic species were revealed in the coastal area of the Dodekanisos Islands. (GIANNUZZI-SAVELLI *et al.*, 2001; CORSINI *et al.*, 2002; GALIL & KEVREKIDIS, 2002; BARNICH & FIEGE, 2003; CORSINI *et al.*, 2003; SALOMIDI *et al.*, 2003).
2004:	Three exotic species (*Colpomenia peregrina, Callionymus filamentosus* and *Sphyraena flavicaudata*) are here reported for the first time from the island of Rodos (present study).

favourable conditions for the establishment of Erythrean species.

THE IMPACT

Invasive species feed on native species, thus eliminating a vital part of the native food chain. Economic and environmental damages occur when exotic species are introduced. The most evident effects of species' invasion can be detected at three different levels, namely biodiversity, economy and human health.

Effects on biodiversity: On the basis of species' 'richness', it seems that more species exist in a given region after invasions. The evidence for endangerment or extinction of native marine species in Hellas at the hands of marine invasions is almost non-existent, although this does not mean that it may not have occurred or may not be occurring.

Effects on economy: Introduction of exotic species has been known to damage the stock of commercial fisheries. An example of invasive species can explain the huge dimension of the problem worldwide:

- The introduction of the European green crab *(Carcinus maenas)* to the east and west coasts of America has been linked to the decline in the scallop fishery in the north-east US. Studies indicate that the green crab has the potential to significantly alter the distribution, density and abundance of prey species and thus profoundly alter the ecology where it has been introduced.

Effects on human health: Some invasive species, such as toxic dinoflagellates and cholera-causing bacteria, can affect human health. The dinoflagellates red tides can cause paralysis and sometimes death in humans who eat affected shellfish. A red tide outbreak in New Zealand was so severe that people breathing the sea air became ill. Ballast water can also transport cholera around the world. In 1991 the South American cholera epidemic was a result of the bacterium discovered in oysters and fish in Mobile Bay, Alabama. One third of the ships arriving at Alabama from South America carried this bacterium.

CONCLUSIONS

Biological invasion is facilitated in degraded environments, subjected to strong pollution pressures and anthropogenic impact (e.g. ports) or by a regression of a native species (e.g. *P. oceanica* recession facilitates *Caulerpa* spreading in the western Mediterranean) or by climatic changes favouring the establishment of new species better adapted to the new conditions. Generally, a healthy native ecosystem is able to overcome invasion. Thus, the identification of possible hot-spot areas of introduction and their monitoring could be the first step towards controlling bioinvasion.

Extreme focus is presently placed on ballast water as a marine invasion pathway, but all the pathways associated with maritime shipping and water exchanges should be considered together for monitoring and management strategies concerned with the prevention of species' introductions. Legislation concerning this issue should extend its scope and consider all pathways associated, not only with maritime shipping, but also with all activities related to active introduction. Thus, although it is unrealistic to stop a physical (or man-mediated but now irreversible situation like Lessepsian migration) phenomenon of homogenisation, it is feasible to stop invasion from other sources.

While we seek to preserve native species' diversity and while we continue to attempt to determine if marine invasions in the ocean are threatening any native biota, we also seek to preserve community (habitat) and ecosystem diversity. It is here, in the preservation and conservation of supra-specific diversity levels, that one of the greatest ecological challenges of marine invasions lies.

VIII.8. ECOLOGICAL STATUS AND TRENDS

Due to the stability and consistency of the benthic element, zoobenthic and phytobenthic communities have long been used for the assessment of the health condition of the marine environment. For macrozoobenthic communities assessment several tools and metrics have been traditionally used and tested such as diversity indices, multivariate techniques, graphical representations and indicator species or groups. The Hellenic experience on using some of them is illustrated below:

Contribution of the animal groups

In undisturbed soft bottom macrozoobenthic communities, the average contribution of the species abundance and variety is shown in Figure VIII.37. In disturbed (polluted or impacted by other human activities) communities, polychaetan and molluscan contribution increases at the expense of sensitive phyla such as the echinoderms or of sensitive taxa of other groups.

Community diversity

The number of species and their relative abundance can be combined into an index that shows a closer relationship to other properties of the community and the environment than would the number of species alone. The Shannon-Wiener diversity index (H), developed from the information theory, has been widely used and tested in various environments. This index depends on sample size and effort and on habitat type and equally should refer to a standard sampling surface. Table VIII.6 presents the range of values of H estimated per habitat type in different areas all over Hellas.

Shannon-Wiener diversity estimations in Hellenic coastal waters range between 1.82 to 6.68. Figure VIII.38 shows the distribution of H in 116 sites all over Hellas. Certainly, community diversity is lowered by severe pollution stress compared with control areas or years. Values lower than 1.50 bits per unit have been calculated in the severely polluted areas of the Saronikos Gulf, between 1.5 and 3 for highly polluted areas of the Thermaikos and Saronikos gulfs, 3-4 for moderately polluted areas, 4-5 for transitional zones and over 5 for normal zones. The maximum values of H coincide with the pristine areas of the National Marine Park of Alonnisos - northern Sporades, the Kyklades plateau, Rodos Island, Ionian Sea and Petalioi Gulf.

Based on the Shannon-Wiener diversity index,

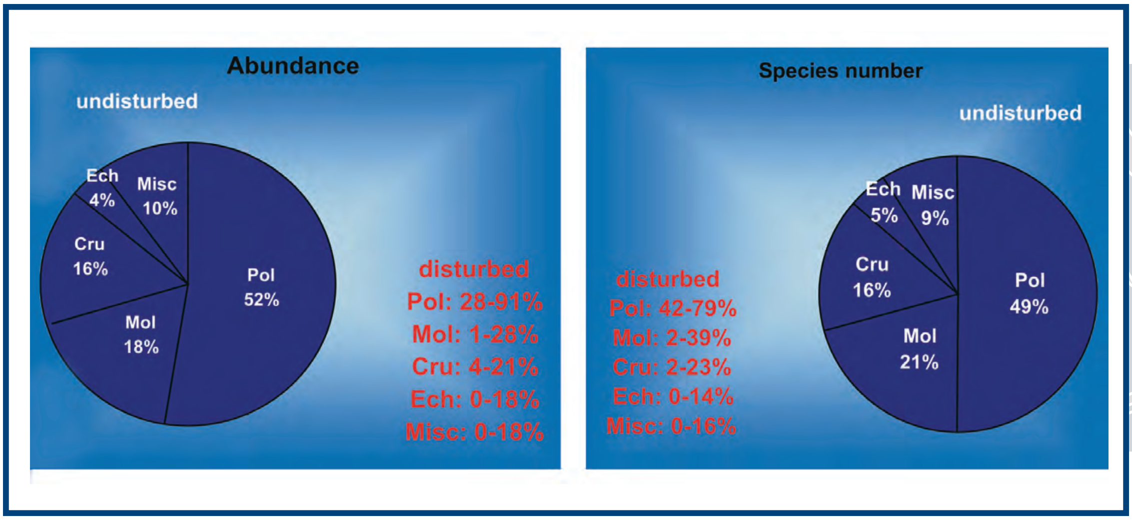


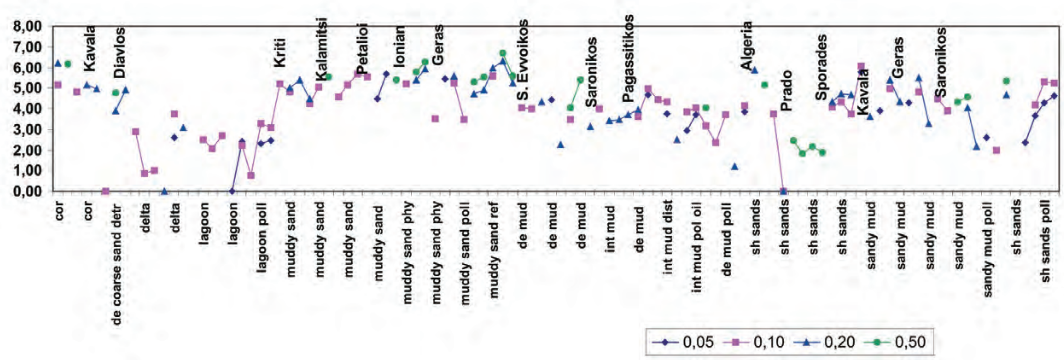
Figure VIII.37: *Contribution of main animal groups. (Pol=Polychaeta, Mol=Mollusca, Cru=Crustacea, Ech=Echinodermata , Misc=various minor taxa).*

community health can be divided into five categories applying mostly to muddy sands or sandy muds marine benthic habitats in Hellenic coastal waters (Table VIII.7). The limits of these classes are somewhat arbitrary, but they are based on long experience of the authors and data series on Shannon's diversity index H).

Table VIII.6: *Range of Shannon-Wiener diversity (H) according to habitat type.*

Habitat type	H min (disturbed to polluted)	H max (undisturbed)
Midlittoral sands	0.57-1.31 (Thermaikos)	1.12-1.40 (Strymonikos)
Muddy sands	3.5 (Saronikos)	5.67 (Petalioi) 6.68 (Itea)
Muddy sands with phytal cover		5.21 (Ionian) 5.95 (Antikyra)
Sandy muds	1.99 (Saronikos)	4.94 (Pagasitikos) 5.42 (Pagasitikos)
Shallow muds	3.17 (Maliakos)	4.35 (Thermaikos) 4.97 (Strymonikos)
Deeper muds	2.36 (N. Evvoikos)	4.04 (S. Evvoikos)
Shallow Sands		5.16 (Milos isl. /Kyklades)
Deeper Sands with detritus	2.87 (Ionian)	5.22 (Ionian)
Shallow muddy sands	2.35 (Geras)	5.23 (Oropos)
Coralligenous	4.84 (Chalkis)	5.16 (Ionian) 6.20 (Ionian)
Bathyal muds	2.77 (Korinthiakos 800m) 2.4 (Cretan Sea 1560 m)	4.46 (NE Aegean 1250 m)

Source: *SIMBOURA & ZENETOS, 2002; TSELEPIDES et al., 2000; UoA (unpublished data).*



Data sources: *HCMR data base.*

Figure VIII.38: *Distribution of community diversity (Shannon-Wiener) over 116 Hellenic sites.*

Table VIII.7: *Ecological quality assessment in Hellenic Seas using the Shannon-Wiener diversity index (H)*

bad	0<H≤1.5	azoic to very highly polluted , Elefsis Bay, Thessaloniki Bay
poor	1.5<H≤3 :	highly polluted , ex. Saronikos, Thermaikos
moderate	3<H≤4 :	moderately polluted
good	4<H≤5 :	transitional zones
high	H>5 :	reference sites

Source: *ZENETOS & SIMBOURA, 2001.*

New metrics developed under the scope of WFD

The concept of the ecological quality status of the benthic quality element acquired special importance since the legislative validation of the Water Directive for the Water Policy (EEC, 2000). According to the Directive all coastal and transitional European waters should be classified to each one of five quality classes ranging from bad to high (bad, poor, moderate, good and high). The basic quality elements for this classification are the macroinvertebrate fauna, the phytobenthos and the phytoplankton. Towards implementing the requirements of the WFD (Water Framework Directive) much effort has been asserted in developing new metrics and classification tools for the zoobenthos and phytobenthos biological elements in compliance with the WFD. Biotic indices are based on the concept of sensitive and tolerant indicator taxa for zoobenthos or late-successional and opportunistic taxa for phytobenthos respectively and provide numerical scales for developing classification schemes. Such biotic indices are the BENTIX index for zoobenthos and the Ecological Evaluation-EEI index for phytobenthos and have been applied with success in several benthic ecosystems in Hellas.

ZOOBENTHOS

The biotic index BENTIX (Table VIII.8) was developed on the basis of former biotic indices (BORJA *et al.*, 2003) and is based on the sum of the percentage contribution of three ecological groups of species with different type of reaction to disturbance. These percentages are enhanced with coefficients based on the realization that the probability of a benthic species picked up randomly, to be tolerant to stress is 3:1. The derived formula gives five ranges of numeric values corresponding to five classes of ecological quality according to the requirements of the EU Water Framework Directive. The boundaries among classes were set after multiple tests with data from sites with known environmental pressures. Among the advantages of the new index are included: independence from habitat type and sample size and simplicity in its calculation and use. It is noteworthy that the Shannon-Wiener Diversity index fails to detect slight disturbance in cases of ecotonal transitional zones where the number of species is fairly high combined with significantly high densities of opportunistic species.

BENTIX = { 6 X (%GI) + 2 X (% GII + % GIII)}/100
where GI: sensitive and indifferent to disturbance taxa
GII: tolerant and second order opportunistic and
GIII: first order opportunistic taxa
Since the same factor 2 is assigned for all tolerant taxa the formula could be more simply expressed as:

BENTIX = { 6 X %GS + 2 X % GT } /100
where GS are all 'sensitive' taxa and GT all 'tolerant' taxa

For purely muddy habitats where the benthic fauna is normally dominated by some tolerant species, and only in the class border among high and good, a possible refinement of the boundary limit would change 4.5 to 4.

The following graphs illustrate the ecological quality and trends of the given water bodies based only on the macrozoobenthic quality element as demonstrated by the BENTIX index. It is thus noted that the Directive requires that the final classification of a water body should be based on the combined estimation of the condition of all biological elements (macrozoobenthos, phytobenthos and phytoplankton) following the one-out all-out principle, taking also into account the condition of the physicochemical and hydromorphological elements.

Table VIII.8: *Classification scheme of soft bottom benthic habitats based on the BENTIX index.*

Pollution Classification	Bentix	Ecological Quality Status (EcoQ)
Normal/Pristine	4,5 ≤ Bentix < 6	High
Slightly polluted, transitional	3,5 ≤ Bentix < 4,5	Good
Moderately polluted	2,5 ≤ Bentix < 3,5	Moderate
Heavily polluted	2 ≤ Bentix < 2,5	Poor
Azoic	0	Bad

Source: *SIMBOURA & ZENETOS, 2002.*

Spatial trends

Applying the BENTIX index in a pan-Hellenic scale to benthic data from the Saronikos Gulf (NCMR, 2001a), the Evvoikos Gulf (NMCR, 1997), and the Kyklades (NCMR, 1989) a gradient of the EcoQ status is evident ranging from moderate in the western axis of inner Saronikos and around Psittalia sewage outfalls to good in the eastern axis of the inner Saronikos Gulf and towards the outer Saronikos (Figure VIII 39). The good quality status zone expands in the southern Evvoikos Gulf, an area slightly disturbed due to pressures such as ports, navigation, tourist development and summer resorts and by fisheries (trawling).

In a micro-scale within the Hellenic environment such a trend including, however, a prominent bad and poor EcoQ status class, is evident along the transect Bay-Gulf of Thessaloniki-Thermaikos Gulf (Figure VIII. 40).

The BENTIX index applied on data from the area covering a long period of monitoring [NCMR, 1994; NCMR, 1996, NCMR, 2001b, FATE project] but focusing on different areas at each period, shows a clear gradient ranging from azoic sites in the port of Thessaloniki to gradually poor, moderate and good towards the opening of the gulf of Thessaloniki, reaching even high status towards the outer Thermaikos Gulf (Figure VIII. 40).

Organic pollution from urban and agricultural wastes discharged in the enclosed Thessaloniki Bay and Gulf results in eutrophication and consequently in the degradation of the benthic element. The pressures on the EcoQ status are more prominent in the more enclosed bay of Thessaloniki declining along the transect towards the opening of the gulf.

Figure VIII.41 shows the EcoQ status plots as demonstrated by the application of the BENTIX index in a sequence of four sampling occasions covering the period 1999-2002. As seen in the Figure the Saronikos Gulf also presents a clear spatial differentiation pattern in the EcoQ status due to the functioning of the Psittalia sewage outfall and also due to important variations of the hydrological and geomorphological factors. The most affected areas, as the benthic communities show, are the area around the Psittalia outfall in

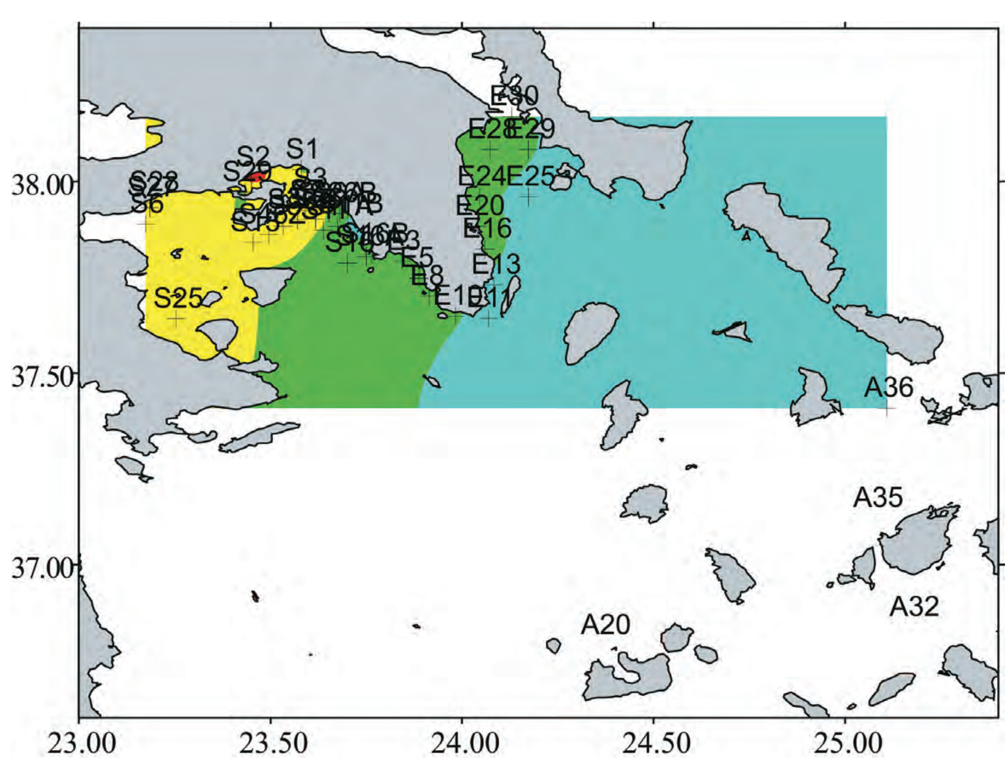


Figure VIII. 39: *Trend of EcoQ status along the axis Saronikos-south Evvoikos gulfs as demonstrated by the BENTIX index method.*

the inner Saronikos Gulf, the Bay of Elefsis, a shallow and enclosed bay, and the western basin (deep and stratified basin).

The inner Saronikos Gulf itself also presents some differentiation of the EcoQ status along the western-eastern axis, and naturally along the axis inner-outer gulf as the distance from the outfall increases.

In the western axis the EcoQ is characterised as moderate while towards the eastern direction the

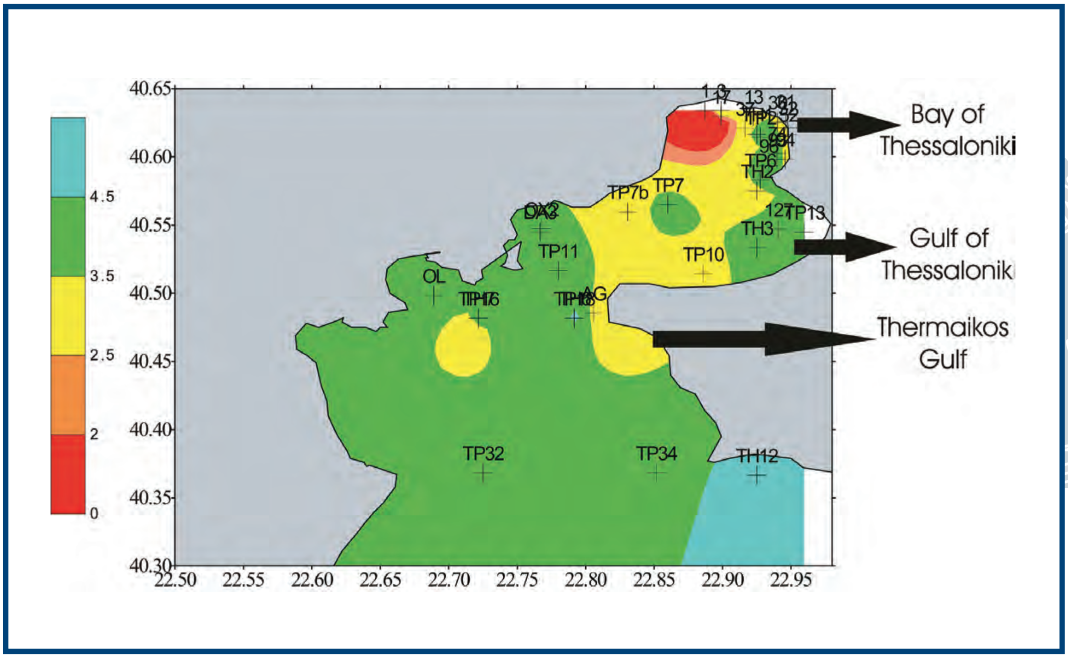


Figure VIII.40. Ecological quality status in Thermaikos Gulf as illustrated by the BENTIX index.

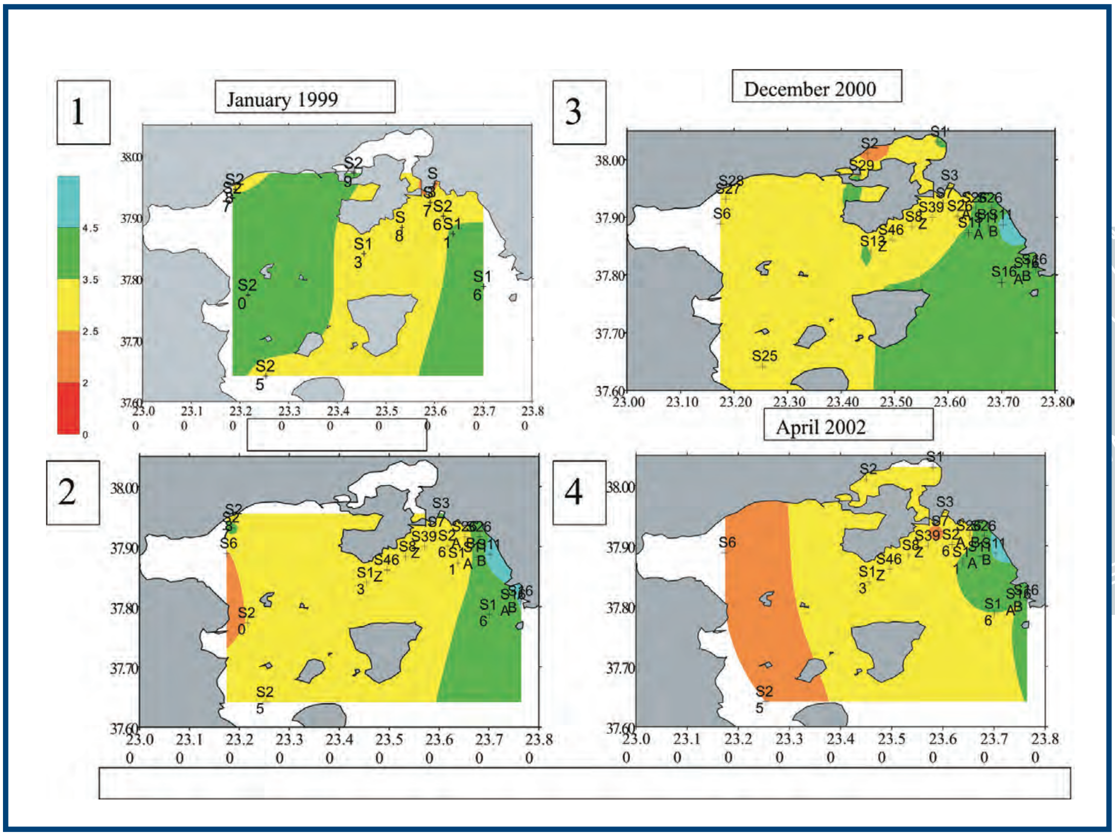


Figure VIII.41: Differentiation patterns and trends of Ecological Quality as defined by the BENTIX index in the Saronikos Gulf benthic communities over the period 1999-2002.

EcoQ status is modified to good and locally reaches the high status near the eastern coast. This differentiation is mostly attributed to the bathymetry, the sedimentology and hydrology; generally the cyclonic hydrological regime of the gulf results into the dispersion of the organic lood towards the south-west of Psittalia area; besides the western area is deeper, with muddy sediments and the communities are more unstable and vulnerable to disturbance.

The eastern area itself presents some internal differentiation of the EcoQ status along the direction towards the shallower coastal areas where at some points the EcoQ status reaches the high class. The deeper areas are more affected by the deep diffusion of the sewage combined with the seasonal stratification of waters.

Temporal trends

Figure VIII.41 also demonstrates some seasonal and interannual trends of EcoQ in the Saronikos gulf and driving factors for such trends are presumably related to the quality and way of diffusion of the sewage effluent through the procedure of the primary treatment plant, combined with seasonal stratification and hydrological conditions.

Based on the sequence of plots of Figure 32 and the general experience in the area the following trends can be detected:

- In the Bay of Elefsis there is a general improvement trend in the EcoQ status especially towards the western outlet.
- In the inner gulf the most outstanding change is the recession of the poor quality zone in the area of Keratsini Bay close to Psittalia shortly after 1999. However the neighbouring area of Psittalia seems to be more prone to shifts in EcoQ status as is evident from the recession of the EcoQ status in April 2002 from moderate to good status. The impact from the deep diffusion of the sewage effluents presumably starts at this point while the stratification conditions which are linked to the seasonal cycle play an important role in defining the degree of disturbance in the benthic element.
- The western basin presents from 1999 to the most recent data (April 2002) a declining trend in the EcoQ status with shifts from moderate to poor status, while in 1999 it was at some points even good. An important process controlling this phenomenon is the trapping of the organic loads into the deeper stratified layers of the basin.

Long-term trends of the EcoQ status are evident in areas of continuous disturbance of the benthic environment where long time-series of data are available e.g. north Evvoikos Gulf dumping site of metalliferous waste-LARKO ferronickel plant (NCMR, 2003).

Figure VIII.42 shows the interaction plot of the BENTIX index applied in the benthic communities

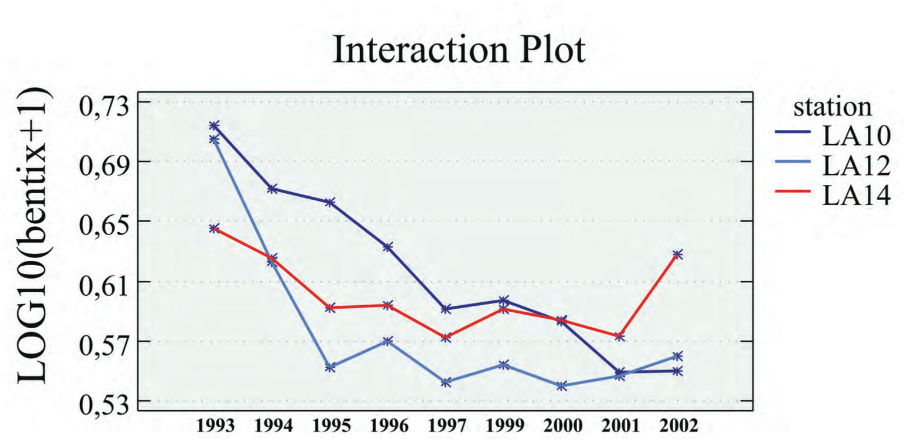


Figure VIII.42: *BENTIX index interaction plot in three stations on a dumping ground (1993-2003)*

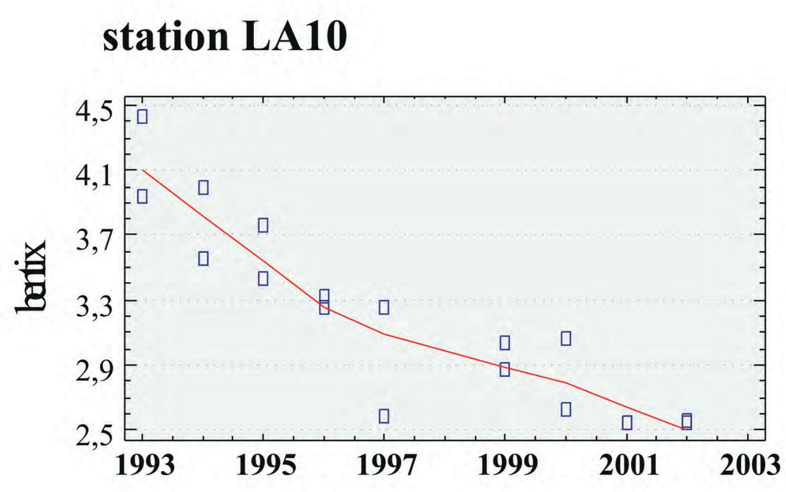
Source: *NCMR, 2003.*

of three sites situated alongside a dumping ground being monitored for the period 1993-2002. Figure VIII.43 shows the trend of decreasing mean annual values of the BENTIX index and dropping ecological quality through this decade at station L10 where the dumping rate had been increasing. In this case although the condition of this biological element is classified as moderate, the hydromorphological elements (structure and substrate of the coastal bed) and the physicochemical elements (pollution by heavy metals) largely deviate from normal. However, the poor or bad ecological status of a water body is only dictated by the condition of the biological element.

PHYTOBENTHOS

The Ecological Evaluation-EEI index is based on the well-known pattern that chronic anthropogenic disturbance, e.g. eutrophication-pollution, shifts the ecosystem from a pristine to a degraded state, where opportunistic species through rapid growth and recruitment are dominant. This pattern can be explained from the species competition abilities under abundant resource conditions and is in accordance to *r*- and K-selection theory.

The EEI evaluates shifts in marine ecosystem by classifying marine benthic macrophytes from their life-cycle strategy in two Ecological State Groups (*K*-selected species=ESG I, *r*- selected species=ESG II). The evaluation of five ecological status classes needs a cross comparison in a matrix of the ESGs and a numerical scoring system. EEI was successfully used in upper sublittoral hard bottom benthic habitats when a seasonal sampling of a site-specific macrophyte climax community, e.g. *Cystoseira, Corallina*, was undertaken. EEI values higher than 6 indicate sustainable ecosystems of good or high ESC, whereas EEI values lower than 6 indicate that the ecosystems should be restored to a higher ESC (Table VIII.9).



Source: *NCMR, 2003.*

Figure VIII.43:
Trend of decreasing ecological quality as demonstrated by the BENTIX index.

Table VIII.9: *Classification scheme of hard bottom benthic habitats based on the Ecological Evaluation-EEI index.*

Pollution Classification	Ecological Evaluation-EEI index range	Ecological Quality Status	Management target
Normal/Pristine	10 < EEI < 8	High	Sustainable
Slightly polluted, transitional	8 < EEI < 6	Good	Sustainable
Moderately polluted	6 < EEI < 4	Moderate	Restoration
Heavily polluted	4 < EEI < 2	Poor	Restoration
Before azoic	2	Bad	Restoration

Source: *ORFANIDIS et al., 2001 & 2003*

The methodology also includes a technique for spatial integration of the results for assessing the ecological status of the whole area delimited by sampling stations.

The EEI was designed to cover the prerequisites of European WFD and to offer to water managers worldwide a tool for comparing, ranking and setting management priorities at different spatial levels without a demand for specialised knowledge in seaweed or seagrass taxonomy.

Spatial trends

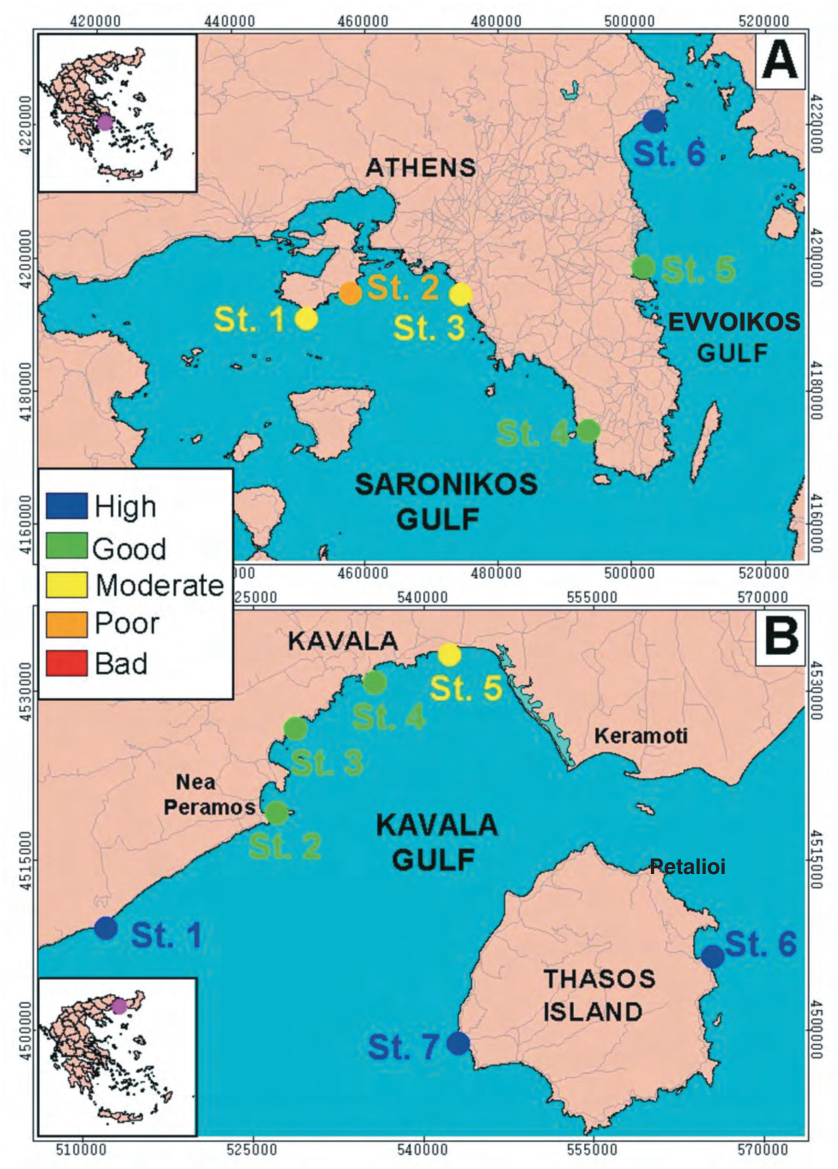
In urbanised Hellenic coasts and embayment sewage discharges, agricultural runoffs and/or industrial effluents in combination have induced long-term changes of the water physical and biological characteristics. Increased sedimentation and nutrient additions have degraded the light climate and resources seriously affecting the benthic vegetation.

Field studies in the sheltered inner part of the Thessaloniki Gulf revealed a reduction by ca. 70% of seaweed diversity in 1970s due to considerable increase of non-cleaned industrial and domestic effluents (HARITONIDIS 1978; NIKOLAIDIS 1985). However, the typical of clear water species *Halimeda tuna, Anadyomene stellata* and *Flabellia petiolata* seem to have disappeared even earlier, in the 1960s. Several perennial and slow growing species, including *Cystoseira* and *Posidonia* meadows, dramatically reduced or disappeared from polluted parts of the Thessaloniki Bay. Today, the littoral zone is dominated by opportunistic fast growing filamentous, e.g. *Cladophora, Ectocarpus*, sheet-like, e.g. *Ulva, Punctaria* and coarsely branched, e.g. *Gracilaria, Gigartina* species.

A similar trend was also described in the semi-exposed Saronikos (DIAPOULIS & HARITONIDIS 1987) and Kavala gulfs. The most human impacted inner areas of the Saronikos Gulf were dominated by fast growing *Ulva* sp. and *Dictyopteris membranacea* species, whereas the outer areas by *Cystoseira* spp., *Jania rubens, Padina pavonica* and *Halopteris scoparia*. In the littoral zone close to the Industrial area and the biological treatment station of urban effluents of the city of Kavala the slow growing species *Corallina elongata* co-existed with the fast growing species *Ulva* sp., *Herposiphonia* spp. and *Cladophora* spp. In the coastal stretch eastern to the city of Kavala (tourist area) extensive meadows of the long-lived species *Cystoseira crinitophylla* and *C. compressa* can be found, however, with *Ulva* or *Cladophora* epiphytes during summer months.

Fishing activities may also alter and degrade directly or indirectly the marine ecosystems especially in coastal areas where fishing is combined with other human disturbance. Indirect effects of fishing can have more serious impacts on the marine ecosystem structure and dynamics than fish removals. Dredging and bottom trawling kills and removes sessile organisms, e.g. seagrass meadows, rhodolithes, that provide critical structures for recruitment, prey protection and sustaining biodiversity. This kind of impact is underestimated in the Hellenic coast and more constructive research is needed in the future. The issue is addressed in detail in Chapter VIII.4.

Applying the EEI index **in a pan-Hellenic scale** to seaweed data from the Saronikos-Pelalioi and Kavala gulfs the disturbance gradient is evident. The Saronikos coasts on a gradual attenuation axes of the human impact caused by the central outfall of urban wastes were classified as poor, moderate and good- Ecological Status Classes-ESC (Figure VIII.44). Sites located in the Petalioi Gulf were classified as good and high ESC. The Kavala coasts on a gradual attenuation axes of industrial, urban and agricultural wastes as well as pressure from tourist development were classified as moderate, good and high-ESC (Figure VIII.44). Two pristine sites in the Thasos Island were classified as high-ESC.



Sources: *(A) PANAYOTIDIS et al., 2004, (B) ORFANIDIS unpublished data.*

Figure VIII.44:
Different Ecological Status classes defined by EEI in two semi-exposed Hellenic coastal ecosystems: Saronikos (A) and Kavala (B) gulfs.

VIII. GAPS IN KNOWLEDGE - FUTURE PERSPECTIVES

- Gaps in the fisheries research include assessing the level of damage that can be sustained and/or is acceptable by the ecosystem through **fishing** practices (ex fishing gears); also secondary effects such as the impact of the partial removal of a predator or a part of a life cycle of one species are unclear. There is no information on fate and survival of discards. The recovery of epifaunal benthic communities and the magnitude and significance of sediment resuspension and associated fluxes are unknown. Future studies approach should be large-scale press and relaxation experimental work coupled with energy budgets that can be used to improve ecosystem models for predictive work.
- Regarding **fish farming** there is a need to develop indicators of environmental health and to produce widely accepted environmental quality standards. This information will aid decision-making on further expansion of the industry, avoiding adverse ecological consequences and undesirable effects on farmed stocks given the large-scale degradation of Mediterranean marine ecosystems due to fish farming wastes under present production levels.
- The real extent of the phenomenon of **exotic species**' transfer is not known. Lists of exotic species are available only for few taxa and often regard a limited geographic extent. Many invertebrate groups (e.q. ascidians) are not known. Solid data about the exotic species' mode of introduction, the rate and patterns of dispersal, their abundance and impact on the ecosystem and native species are lacking. Studies directly investigating the impact of exotic immigrants on the diversity of autochtonous biota as well as socio-economic impact from exotic species causing.
- Co-ordinated, cooperative regional research is needed to investigate the phenomenon, particularly in pollution susceptible areas such as ports and lagoons (one project currently in progress, run by the University of Athens, investigating the phenomenon in Peiraias, Thessaloniki, Irakleio and Kalamata ports – 2003-2005).
- The Water Framework Director poses the EU member-states the obligation to assess and conserve to a good state the **ecological status** of all surface water bodies using the biological elements. The already developed tools require testing with data from other regions of the Mediterranean, and also testing other metrics with national data is needed. This is the task of intercalibration which is a requirement of the WFD already in process.

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ACRONYMS

ABC	Abundance-Biomass-Comparison
AdBW	Adriatic Bottom Water
ADW	Aegean Deep Water
AHP	African Humid Phase
AIS	Atlantic Ionian Stream
AW	Atlantic Water
BAC	Beam Attenuation Coefficient
BB	Bacterial biomass
BNL	Bottom Nepheloid Layer
BP	Before Present
BSW	Black Sea Water
CDW	Cretan Deep Water
CFP	Common Fisheries Policy
CITES	Convention on International Trade of Endangered Species
CIW	Cretan Intermediate Water
CSW	Cretan Surface Water
DCM	Deep Chlorophyll Maximum
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
ECMWF	European Centre for Medium-Weather Forecasting
EcoQ	Ecological Quality Status
EEI	Ecological Evaluation Index
EMDW	Eastern Mediterranean Deep Water
EMT	Eastern Mediterranean climatic Transient
ERSEM	European Regional Seas Ecosystem Model
ESC	Ecological Status Classes
FAO	Food and Agriculture Organisation
FEAP	Federation of European Aquaculture Producers
FiB	Fisheries in Balance
GBD	Gross Domestic Product
GDR-M	Merged Geophysical Data Records
HCB	Hexa-chloro-benzene
HCHs	Hexa-cholo-hexanes
HCMR	Hellenic Centre for Marine Research
HNF	Heterotrophic Nanoflagellate
IA	Ionian Anticyclones
ICCAT	International Commission for the Conservation of Atlantic Tunas
IGME	Institute for Geology and Mineral Exploration
INL	Intermediate Nepheloid Layers
ISD	Index of Size Distribution
ISW	Ionian Surface Water
LBS	Land Based Sources
LDW	Levantine Deep Water
LGM	Last Glacial Maximum
LT	Light Transmission
LIW	Levantine Intermediate Water
LWC	Locally Weighed Regression

MAGP	Multi Annual Guidance Plans
MMJ	Mid-Mediterranean Jet
MRU	Motion Reference Unit
NAF	North Anatolian Fault
NAT	North Aegean Trough
NCEP	National Centres for Environmental Prediction
OECD	Organisation for Economic Cooperation and Development
PON	Particulate Organic Nitrogen
PB	Phytoplankton Biomass
PCBs	Polychlorinated Biphenyls
PFP	Phosphoric Fertilizer Plant
PM	Particulate Matter
PMC	Particulate Matter Concentration
PON	Particulate Organic Nitrogen
POPs	Persistent Organic Pollutants
PP	Primary Production
ROV	Remotely Operated Vehicle
SCI	Sites of Community Interest
SHV	Shallow Hydrothermal Vents
SMB	Sverdrup-Munk-Bretshneider
SNL	Surface Nepheloid Layer
SOWM	Spectral Ocean Wave Model
SPA	Special Protected Areas
SST	Sea Surface Temperature
T/P	Topex / Poseidon
T/S	Temperature/Salinity
TACs	Total Allowable Catches
TMF	Total Mass Flux
TMW	Transitional Mediterranean Water
TOC	Total Organic Carbon
UWM/COADS	A data set produced at the University of Wisconsin-Milwaukee. Monthly fields were derived from the *COADS* data set *Comprehensive Ocean Air Data Set*
VTC	Coastal Terrigenous Muds
WAM	WAve Model
WBT	Water Body Type
WFD	Water Framework Directive
WGITMO	Working Group on Introductions and Transfers of Marine Organisms
WWTP	Waste Water Treatment Plan
YD	PhaseYounger Dryas

H.C.M.R

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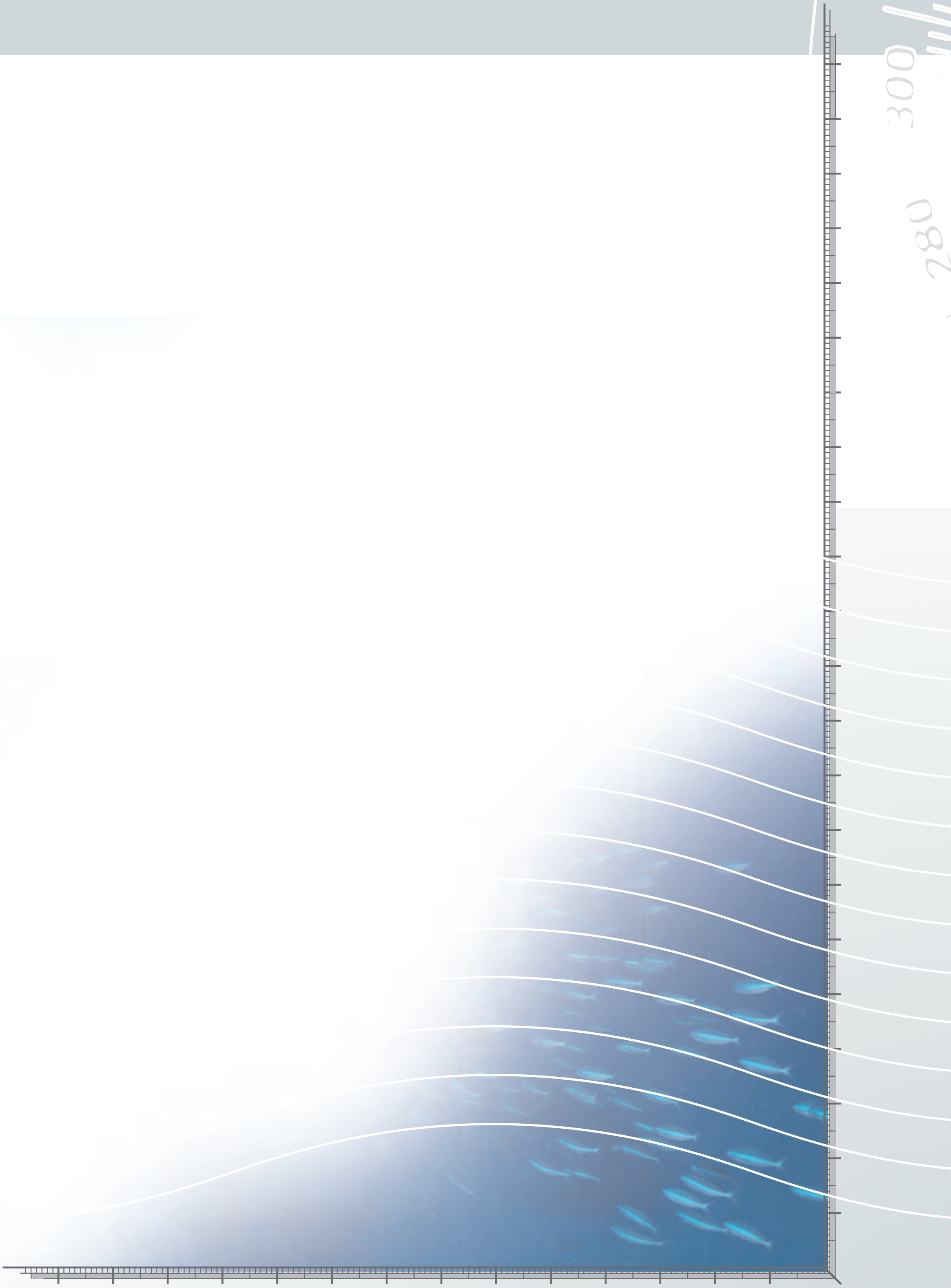

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