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"The Mediterranean Sea as a Large Ecosystem"
"How Could the Mediterranean Ecosystem be Endangered?"
"Response of the Mediterranean Ecosystem to Physical Forcings"

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The Mediterranean Sea as a Large Ecosystem

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1

History

- The Mediterranean Sea is the remains of the ancient Tethys, a large sea adjoining Eurasia, to the north, and Gondwana, to the south.
- The present basin is modern. It originated during the Alpine formation by interaction of the two continents and is still in continuous evolution.

2

Morphology

- The Mediterranean Sea is a considerably deep basin (average 1500 m, maximum 4500 m) subject to the geodynamical processes characteristic of the oceans (plate drift, mid-ocean rifts, subsiding margins, etc.).
- The two main basins (eastern and western) joined by the Sicilian Channel, are further subdivided by island arches and peninsulae into various sub-basins with various degrees of flow restrictions.

3

Geographic Setup

- Between Eurasia and Africa, the Mediterranean Sea opens up to the Atlantic Ocean to the west and communicates with the Red Sea and the Indian Ocean to the east through the Suez Canal.
- Between the 30 °N and 45 °N, it is exposed to the W - NW winds, strong insolation and low precipitation typical of the Subtropical Zone.

4

Characteristics

- Extension: 3800 km E - W and 800 km N - S
- Area: $2.5 \cdot 10^6$ km^2
- Volume: $3.7 \cdot 10^6$ km^3
- Average depth: 1500 m
- Maximum depth: 5100 m (central Ionian Sea)

5

A negative estuary

- The Mediterranean Sea has some of the characteristics of an estuary (e.g. large N:P ratios).
- However, because of the low runoff received (smaller than the rate of evaporation), it has been described as a negative estuary (exports dense/salty/deep water instead of light/fresh/surface water).

5

Hydraulic Balance

Process	(m3/s)
Evaporation	95000
Precipitation	28000
Runoff	14000
Net Balance	-53000
Net inputs through:	
Dardanels	6000
Gibraltar	54400
Sicilian Channel	43000
Total Inputs through:	
Dardanels	12500
Gibraltar	1187500
Sicilian Channel	1000000

Hydrodynamic Consequences

- The Mediterranean is an evaporation basin with salinities above the oceanic mean.
- The hydraulic balance requires input of low-salinity surface water from the Atlantic ocean and output of high-salinity intermediate and deep waters to the ocean.
- The dynamic equilibrium generates a general cyclonic circulation.

Water masses

- Apart from the Modified North Atlantic Water and other water masses of only local interest, three major water masses fill up most of the Mediterranean Sea:
  - Eastern Mediterranean Deep Water, formed in the Mid Adriatic and Aegean seas.
  - Western Mediterranean Deep Water, formed in the Gulf of Lions.
  - Levantine Intermediate Water, formed off Rhodes and Cyprus, floods both basins.

Age of a water mass

- The age of a water mass is considered to be the time elapsed since it was last at the surface (oxygen and other gases equilibrated with the atmosphere).
- The most recent waters in the entire ocean are those formed in the North Atlantic (Sea of Greenland, Sea of Iceland and Labrador Sea) and in the Antarctic (Sea of Weddell).

Age of the Mediterranean waters

- The mean renewal time of the entire Mediterranean basin is of the order 90 yr.
- The mean renewal time of the western basin is less than half.
- The youngest waters are probably the EMDW and WMDW.
- The oldest water (highest nutrient concentration) is the LIW in Alboran Sea.

Nutrient distributions

- The Mediterranean Sea waters are known to have smaller nutrient concentrations than waters at equal depths in the oceans ?
- The nutrient-poor incoming Atlantic surface water is further depleted as it progresses eastwards, thus enhancing the poverty of the Eastern Mediterranean basin.
- On the contrary, the progressive westwards enrichment of the deep water enhances the net nutrient losses to the ocean.

Nutrient chemistry

- The nutrient concentrations of the deep and intermediate waters are produced by the mineralization of mostly particulate organic matter falling from the euphotic zone.
- Nutrient recycling processes may take place at three time scales :
  - Long term
  - Medium term
  - Short term

13

Long-term recycling

- The long-term (time scale of the mean renewal time) recycling of nutrients in the Mediterranean is an open question mark since it encompasses a critical balance between:
  - inflow of nutrient-depleted oceanic water
  - inputs through runoff and river discharges
  - inputs through the atmosphere
  - outflow of nutrient-rich Mediterranean water
  - burial of nutrients in the sediments

14

Medium-term recycling

- The nutrients are transported upwards (advection and diffusion) from intermediate waters and discharged directly to the euphotic zone through runoff and riverine and atmospheric inputs.
- The microplanktonic producers are fed by *new* nutrients and fall down (directly or through production of faecal pellets/marine snow) to be mineralized by the action of deep heterotrophs.

15

Short-term recycling

- Part of the biomass photosynthetically produced (small particles, exudates, etc.) is lost within the euphotic zone and sustains the microbial loop.
- The photosynthetic components of the microbial loop (picoplankton/bacterio-plankton/microflagellates) are fed by nutrients regenerated within the euphotic zone.

16

Nutrient ratios

- The Mediterranean Sea waters are known to have N:P ratios (22:1) well above the Redfield ratio (16:1) found in most parts of the oceans.
- Atmospheric fallout, river water and sewage waters have much greater N:P ratios (300:1 in the Ebro river; 150:1 in atmospheric aerosol at Blanes, e.g.).

17

The Mediterranean nutrient paradigm

- If all the external sources of nutrients have N:P ratios well above those of the oceans interior, why should one expect to find Redfield ratios in any body of water ?
- When the long-term recycling is governed by the biological processes (assuming that the organic material tends to have Redfield ratios).

18

The age of intermediate waters

- Waters in the ocean have obtained their nutrient concentrations due to water renewal times in the order of millions of years.
- The Mediterranean Sea waters with, at most,100 years of recycling, reflect better the relative proportions in the inputs than the internal biological cycling.

19

A large ecosystem ?

- The Mediterranean Sea is a system formed by various subsystems and components each of which may have independently driven processes and interactions.
- Yet, the components interact with each other, in a complex manner, giving rise to an integral, higher order system with a general identity and functional role in the global ocean.

20

Contribution to the Global ocean

- The Mediterranean outflow, of the order of 1 Sv (10^6 m^3 s^{-1}) high salinity water, enters the Atlantic ocean seeking the equilibrium depth
- Strongly diluted with adjacent NADW and AAIW, it spreads around the shelf of the Iberian Peninsula and towards the N-NW.
- The high-salinity of the Mediterranean outflow contributes to the characteristics of the NADW and most other deep waters.

21

The European context

- The Mediterranean Sea covers a surface much larger than the adjacent Atlantic ocean, the North Sea, the Baltic Sea and the Norwegian Sea together.
- Most of the above regional seas are shelf areas, the Mediterranean Sea is a true ocean albeit with 1/5 the dimensions of the Atlantic ocean.

22

How could the Mediterranean Ecosystem be Endangered ?

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Marine Environmental problems

- Local problems
- Coastal problems
- Global problems

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Global problems

- Warming
- Sea-level rise
- Changes in the circulation patterns
- Spring blooms
- Coccolithophorid blooms
- Discolouration of corals
- Species extinction
- Species invasion

3

Local problems

- Chemical pollution
- Eutrofication
- Hypoxia/Anoxia
- Algal blooms (*Phaeocystis*)
- Exocellular products (*Mucillagine*)
- Toxic dinoflagellates
- Jelly fish swarms

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Eutrophication

- Nevertheless, some coastal zones are subject to strong trophic pressure due to the discharge of organic and inorganic nutrients. Examples are the North Adriatic, the Gulf of Elevsis or some highly populated enclosed bays. In such places, the water renewal is insufficient for the dilution of the nutrients supplied mainly anthropogenic.

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Blooms

- Occasionally, in eutrophic zones, there may be overproduction of algal biomass in a thin surface layer (generally in low-salinity water) which is not immediately equilibrated by losses through physical processes or grazing. Algal blooms are then formed which may also be toxic to other organisms or men.

6

Anoxia

- When the biomass produced does not disperse onto a larger area, it settles right onto the bottom and/or makes subsurface layers feeding oxygen-consuming heterotrophic organisms (mostly bacteria).
- Under restricted circulation conditions, anoxia may be produced with the result of fish killings and/or migration.

7

Mucillage

- When nutrients (N:P) are in disequilibrium (mostly in estuarine areas), the phytoplankton organisms may produce exocellular mucillaginous polysaccharides that may accummulate in places with restricted circulation causing ecologic and esthetic problems.

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Toxic Algae

- More and more frequently and with greater intensity, blooms of algae (mostly dinoflagellates) appear that are toxic to the marine organisms or man.
- Even though they seldom produce real blooms (thus with small esthetic or ecologic impacts) the effects may be devastating to bivalve mollusc growers.

9

Degradation of coastal zones

- The degradation of the coastal zones may have several origins not always associated to the discharge of polluted waters.
- Excess fishing, aquaculture, construction of infrastructures (roads, railways, commercial or pleasure harbours, etc) are highly degrading.

10

Coastal problems

- Coastal erosion
- Beach *recovery*
- Modification of the coastline
- Changes in the river loads

11

Response of the Mediterranean Ecosystem to Physical Forcings

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Ecology

- The high insolation, strong stratification and the nutrient export in Gibraltar make the Mediterranean an oligotrophic sea.
- The narrow continental shelves and the low nutrient loads discharged along the coastline strongly limit the coastal productivity.
- The open-sea waters are often more productive than the coastal waters.

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The Mediterranean Paradox

- Topic: The Mediterranean is the most empoverished large body of water known (Ryan, 1966).

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The paradox

- Paradox: Il démeure sans doute vrai que, par comparaison avec les autres mers, la production primaire planctonique en Méditerranée est plus intense que ne le laissent supposer les faibles concentrations en sels nutritifs et la pauvreté des ressources halieutiques (Sournia, 1973)

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The Primary Productivity

- The primary productivity in the open waters of the Mediterranean Sea is in the order of 60 - 90 gC $m^{-2} yr^{-1}$ (Margalef, 1985; Estrada et al., 1985).

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What does it mean ?

- The mean productivity is similar to the average of the global ocean (50-100 g $m^{-2} yr^{-1}$).
- The coastal zones, except for the effect of the continental water discharges, are even poorer than the central parts of the basins.
- Except for some areas with limited extension, the Mediterranean has well oxygenated waters.

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Phytoplankton distribution

- The planktonic communities are directly linked to the fertilization processes.
- The geographic distribution of plankton coincides with the most important hydrodynamic features.
- The vertical distribution of plankton is bound to the thermal structure of the water column.

T7

Pelagic System

- In the open-sea areas, the phytoplankton is preferentially found at the base of the euphotic zone, where it forms a nitracline that insures the vertical flux of nutrients required for the maintenance of a relatively low production both in summer and in winter and a moderate one in spring.

T8

Neritic System

- In coastal zones over the shelf , the phytoplankton distribution is similar to that of the oceanic pelagic system, with a maximum on the bottom.
- This maximum is absent when the bottom is too shallow. Thus, the bottom does not seem to be an important nutrient source in well oxygenated areas.

T9

Estuarine Systems

- The estuarine systems (deltas) are, in the Mediterranean, external plumes floating over nutrient-poor coastal sea water.
- Mostly due to the rapidly changing conditions (mixing/dispersion) these plumes do not allow the development of dense phytoplankton communities.
- The North Adriatic is an exception.

T10