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CAUSES AND EFFECTS OF TERRESTRIAL RUNOFF AND RIVERINE OUTFLOW ON BRACKISH/COASTAL MARINE FISHERIES ECOSYSTEMS IN THE NORTHERN MEDITERRANEAN REGION

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INTRODUCTION

The Mediterranean system (Figure 1) is composed of two semi-enclosed entities: The Mediterranean Sea, itself subdivided into several sub-basins (Adriatic, Ionian, Aegean) and the Black Sea to which the Sea of Azov is attached.

Exchanges between this system and the outside are minimal. Oligotrophic, well-oxygenated Atlantic surface water enters from the west by a single connection, the Strait of Gibraltar. To the east, very limited exchange takes place via the Suez Canal, which allows Indopacific species to arrive on a regular basis (these currently account for up to 30 percent of local commercial catches; Charbonnier and Caddy, 1986). The fauna of the Red Sea has been better than that of the Atlantic at colonizing the Mediterranean, considering the number of species that have entered and have become acclimatized (Vadiya and Shenuda, 1985; Ben-Tuvia, 1973).

Exchanges between the Mediterranean and Black Seas occur in both directions via two narrow straits, the Dardanelles and the Bosphorus (Oguz *et al.*, 1990), and the Sea of Marmara which lies between them. Water circulation within the Mediterranean itself is very slow, largely because of major sills that isolate the various basins. The entrances to the Adriatic and Aegean Seas are obstructed by sills. Other sills occur between Sicily and Tunisia and between the western and eastern Mediterranean. This partitioning leads to differentiation between these isolated areas in terms of physico-chemical and biological properties. For example, the Aegean Sea and eastern Mediterranean are oligotrophic, whereas the Black Sea and Adriatic have been subject to increasing eutrophication in the last decade and undergo anoxic episodes. The Mediterranean system has been described (Malanotte-Rizzoli and Hecht, 1988) as an evaporative basin, because surface evaporation greatly exceeds precipitation, the level being maintained by oceanic (Atlantic and Red Sea) and various riverine inputs.

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The population of the circum-Mediterranean countries was 386 million in 1990 and will reach 491 million in 2010. These figures exclude the seasonal influx of tourists who are estimated to amount 100 million per year (CEFI, 1992). This demographic development and related activities (tourism, agriculture and industry) are certain to have direct and/or indirect effects on terrestrial runoff of freshwater into lagoon and coastal ecosystems, and of course on the entire Mediterranean Sea.

In this article we will therefore attempt to analyse the current causes and effects of terrestrial runoff and riverine outflow on brackish and coastal marine fisheries ecosystems in the northern Mediterranean regions in σorder to promote consideration of these factors in the management and development of this region.

1. THE IMPACT OF LARGE RIVER SYSTEMS ON COASTAL AND FISHERIES ECOSYSTEMS

INTRODUCTION

Most of the freshwater entering the Mediterranean comes from southward flowing rivers. The Rhône, Po and Ebro (Table 1) are the major inputs of freshwater into the Mediσterranean sensu stricto, where these three rivers and the Nile River account for 43 percent of the inflow of inland waters (Cσid Montanes *et al.*, 1990). The impact of the Nile is now very reduced since the commissioning of the Aswan Dam in 1965.

Table 1

Characteristics of the three main rivers in the northern Mediterranean Region

	Catchment area (km^2)	Flow ($m^3 S^{-1}$)	Total annual freshwater input (km^3)	Length (km)	Number of engineering works
Ebro	88 835	550	17	908	25
Rhône	94 000	1 710	55	812	48
Pô	69 000	1 550	48	648	?

River watersheds situated to the north of the Mediterranean include either highly populated industrial regions or less populated agricultural regions. Rivers have been managed for hydroelectricity production, for agricultural production and for inland waterways traffic. Towns have developed indirectly; the number of inhabitants and industrial activity are constantly increasing.

The impact of a river includes both the direct effect of the river itself and the modifications of this influence.

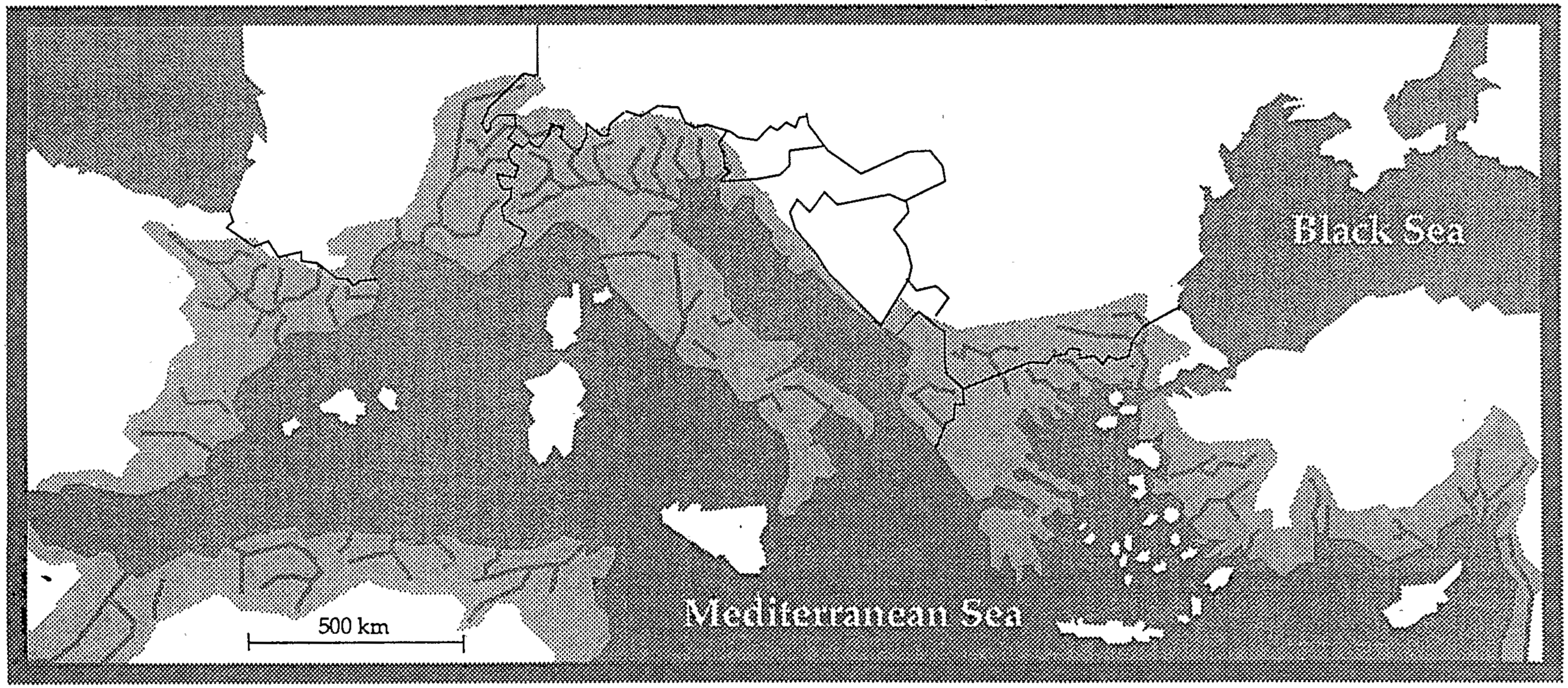

Figure 1. Map of the northern Mediterranean region. The Mediterranean catchment (shaded area) with the main rivers of the northern Mediterranean basin

The direct influence includes:

- physical impact: due to water discharge that plays a flushing role in estuaries; when floods arrive in the sea they may cause physical disturbances liable to bring nutrient-rich subthermoclinal waters into the euphotic zone. Fluvial sedimentation occurs offshore of estuaries and deltas.

- natural chemical impact: the input of freshwater can create saline fronts where river water and saline marine waters meet.

- man-made chemical impact: all discharges of human origin (nutrients, chemical products, heavy metals, pesticides) occurring in effluents or coming directly from the watershed enter the rivers.

This direct influence has been modified as a result of the many changes that have been made to river courses and within their catchments. These modifications comprise mainly land use changes (increased agriculture, deforestation, hydroelectric dams, inland waterways, engineering works to improve navigation, and water diversion for irrigating crops).

These works lead to:

(a) a quantitative decrease in freshwater inputs to the sea, and also a regulation of these inputs which no longer occur according to seasonal weather patterns but depend on agricultural and industrial demands;

(b) a sharp increase in all discharges of human origin (nutrients, chemical products, heavy metals, pesticides);

(c) a very great reduction in the supply of sediment, the immediate consequence of which is a transformation of deltas and coastal areas, and

(d) prevention of upstream migration of marine fish that spawn in rivers (sturgeon, shad and lampreys). Through lack of adequate recruitment these populations quickly disappear from estuarine ecosystems. This disappearance is all the quicker if engineering works are sited in the lower reaches of the river. Sometimes if the dams are equipped with fish passages, these populations are able to maintain themselves, but usually with reduced numbers.

State of the Fisheries

The Mediterranean has always been considered to be oligotrophic and typified by its low rate of turnover of the water mass. Nutrients (phosphates and nitrates) originate both from riverine inputs and from upwelling that brings decomposition products of organic matter to the surface. Renewal of dissolved oxygen takes place with difficulty because of the limited exchanges with adjoining seas (Oliver, 1983). The prolonged retention time is of paramount importance with respect to the accumulation of toxic products and to a lesser extent nutrients. This, and the topographic isolation of some areas has led to individualization of the fisheries of various basins.

In the last few decades, a very clear increase in fish catches (pelagic and demersal) has been recorded. In most of the sub-regions this increase has been about 3-6 percent per year and led to an annual catch of about 1.5-2.0 million tonnes in 1984-87 in the Mediterranean Sea alone. The rate of increase in catches of small pelagic species (generally underexploited) was about 4 percent per year, but with very strong spatial and species variability: 16 percent for the sardine, 2 percent for the anchovy and stability for the bogue (Boops boops). For demersal fish the increase is of the order of 3-8 percent per year, which cannot be explained just by increased fishing effort. It is nevertheless true that the demersal resources of the Mediterranean have been subjected to a continual increase in fishing effort over the last 10-15 years, to the point where it has now reached a level that is already considered as being excessive (Caddy and Griffiths, 1990). In the Mediterranean, pelagic and demersal catches are roughly equal (55 percent and 45 percent, respectively).

At the start of the 1970s, the Mediterranean commercial fisheries yield (sensu lato) was 0.24 tonnes/km^2 (Gulland, 1972) compared to that of the world's oceans (0.16 t/km^2). Both these yield figures have since increased; they were recently 0.8 t/km^2 and 0.25 t/km^2 (FAO, 1988).

These data do, however, need to be put in context. Catches mainly take place on the continental shelf, which accounts for 24 percent of the sea area in the Mediterranean, compared to less than 8 percent of the world's oceans as a whole. In contrast to the above yield figures which show the Mediterranean to be ahead, the fishery yield per unit area of continental shelf is actually of the same order of magnitude in the Mediterranean as in the oceans as a whole. Since 1972, the Mediterranean continental shelf yield has therefore become close to the world average.

There could be many explanations for these increases: (1) more reliably reported fisheries statistics; (2) an increase in fishing activity, and (3) an increase in the productivity of the ecosystem by eutrophication. For example, in Egypt, improvements made to the statistical system since 1983 account in part for the increase in total Egyptian catches from 140 000 t in 1983 to 250 000 t in 1988 and to more than 300 000 t in 1990. But the increases due to improved reporting are undoubtably superimposed on an actual increase in yield (the total catch includes catches from the Mediterranean, Red Sea, lagoons, freshwater and from aquaculture). Mediterranean catches only account for 10 percent of these tonnages (from 22 000 t in 1986 to 32 000 t in 1990). As far as Mediterranean Thunnidae are concerned, all three hypotheses are involved (FAO, 1989). The current trend could also reflect an increase in the area of the continental shelf and slope that is exploited. Whatever the causes, examination of the data for individual regions shows that the areas with the greatest increase in fishery yield are the semi-enclosed sea basins (Adriatic, Black Sea and Aegean). The three explanations may work together in explaining this improvement in fisheries, but at present nothing can be proven.

There are however indications that favour the so-called marine eutrophication hypothesis:

(a) the semi-enclosed basins mentioned above are more liable to be subjected to increased nutrient concentrations; (b) the low-productivity Eastern Basin now also receives few inputs since the existence of the Aswan Dam (1965-67), and (c) the Southwest region, that is also rather unproductive although receiving nutrients, communicates directly with the Atlantic and cannot therefore store them. In addition it has been shown that mixing between different depth layers occurs here.

Let us look in more detail at the third hypothesis, eutrophication.

A workshop on eutrophication in the Mediterranean (Unesco, 1988) revealed that this phenomena has now taken on a major dimension in many coastal areas. It was recognized that eutrophication has had apparent effects on the fauna since it is the cause of "red tides" and has modified benthic communities, formerly typical of clean sandy substrates, but now associated with organic or sandy muds with low interstitial oxygen concentrations (Caddy and Griffiths, 1990).

Because of the limiting nature of nutrients in natural marine oligotrophic environments, it would therefore seem that there has been an increase in biological production in coastal areas in recent years, at least in sites where the capacity of the absorption system has not been exceeded. The absence of consumption of the phytoplankton produced provokes an explosion in its biomass, which can lead to "red tides" (Bernard, 1990). The effects of eutrophication have tended to extend towards offshore regions in some areas. Moderate levels of eutrophication can be beneficial for fisheries in oligotrophic environments, by increasing phytoplankton production, but they often lead to a change in the dominant species and a decrease in the number of species in the ecosystem. In the long term, because of the long retention time of Mediterranean waters, the effects of discharges of nutrients are worrying.

Eutrophication has become a commonplace phenomenon in the coastal areas of the Mediterranean, probably related to development of the agricultural, industrial and urban sectors. As far as the agricultural sector is concerned, fertilizer consumption has increased strongly in the circum-Mediterranean countries (FAO, 1987). Between 1970 and 1985, these increases amounted to 300 percent in some southern countries and 40 percent in the northern countries.

From the literature, nutrients supply, leading to eutrophication of the marine environment, seems to be the major effect of riverine inputs (Caddy and Griffiths, 1990). This eutrophication may be both beneficial and deleterious for fisheries (Lee *et al.*, 1991). In several regions of the Mediterranean, this has assumed non-negligible proportions, particularly in the Adriatic, the Black Sea and in lagoons and estuaries.

The case of the Adriatic Sea

The northern extremity of the Adriatic is a typical example of a shallow sea, lying on a continental shelf (500 km by 200 km). Vukadin (1991) estimated that the annual input of freshwater into the Adriatic is 162 500 x 10^6 m^3/year. Discharges of various origins are made via rivers (Isonzo, Piave, Po, Reno, Oghia, Esino, Tronto, Fortore, Krka, Nerevta, Cetina, Mirna and Rasa) and also from diffuse coastal runoff. The Adriatic receives a major discharge of freshwater from north-west Italy, estimated at 3 097 m^3/s. The Po, with a mean discharge of 1550 m^3/s is the dominant river, contributing 50 percent of the total (Artegiani, 1983). It is one of the major sources of supply of relatively cold low-salinity water from the coast to offshore. The wind plays a secondary role, irrespective of the season, except in occasional periods of NE winds.

During the period from the end of autumn to winter, the waters of the upper and mid-Adriatic are uniform with depth, from the surface to the bottom (250 m on average in the Adriatic) (Malanotte-Rizzoli and Bergamasco, 1983). Waters from the Po are then confined to a coastal strip, forming an extremely stratified zone 10 to 20 km wide. From the end of spring to summer, the situation changes. The discharge of the Po gives rise to two turbid plumes. The Italian coastal zone to the south of the Po delta is stagnant. There is a remarkable stratification in the shallow upper Adriatic; the surface layer consisting largely of freshwater covers a deep layer of warmer saline waters originating from the south.

Eutrophication has been apparent in the Adriatic since the mid-1970s and in 1987 extended beyond the coastal zone (Caddy and Savini, 1988; Vukadin, 1991). According to Revelante *et al.*, (1985), the biomass of microzooplankton has increased 2 to 3-fold in the northern Adriatic near the mouth of the Po, along a east-west trophic gradient. This phenomenon is closely related to the increase in phytoplankton and to eutrophication (Revelante and Gilmartin, 1983). Vukadin (1991) calculated the nutrient balance of the Adriatic and clearly showed that the River Po and discharges from other rivers in northern Italy are the source of and direct cause of eutrophication and phytoplanktonic blooms in the Adriatic. Meteorological and hydrological conditions are responsible for the spreading and persistence of blooms in the northern and central Adriatic.

Correlations have been established between exceptional discharges of the Po, due to heavy precipitation, and phytoplankton blooms (Malanotte-Rizzoli and Bergamasco, 1983). The discharge can attain 1 800 m^3/s at the main outflow, compared to an average summer discharge of 900 m^3/s. These lead to chlorophyll a concentration of up to 250 mg/m^3 in the coastal zone. Increased inputs have therefore probably led to an increase in primary production of the offshore waters, leading in turn to the current high level of sardine production in the mid-Adriatic. This has however sometimes produced locally anoxic conditions in the upper Adriatic, with massive seasonal fish kills (FAO, 1989).

In the summers of 1988 and 1989, the massive production of benthic diatoms covered the bottom in many shallow areas of the northern Adriatic with a thick carpet, leading to death of the benthic fauna through lack of oxygen (Penna *et al.*, 1990; Penna *et al.*, 1993). Littoral spawning sites were of course affected. At present it is impossible to determine the exact cause (nutrient supply, low turnover of the water masses, or yet other hypotheses). All the phenomena cannot yet be clearly explained and authorities disagree amongst each other.

For example, according to Scaccini-Cicatelli (1983), these discharges have no influence on nutrient concentrations in the waters of the Adriatic. This author based his conclusions on the fact that the Po has two periods of maximum discharge (spring and autumn) whereas the nutrients in the sea have a single maximum in winter and a single minimum in summer.

During the 1970s, demersal fish catches in the Adriatic varied between 44 000 and 86 000 tonnes per year while those of pelagic species were between 72 000 and 95 000 tonnes (Oliver, 1983).

Formerly the important sardine catches showed cycles of 11-12 years and were related to stronger than normal arrivals of Mediterranean waters, which were then richer in nutrients (Regner and Gacic, 1974). A 40-year set of data (Pucher-Petkovic *et al.*, 1988) confirmed that turbidity and primary production have increased, to the point where these major influxes of Mediterranean water into the Adriatic are no longer the factor that determines greater than normal sardine catches. Nowadays nutrients originate from the land not from the sea. Recent observations of apparently cyclical variations in the predominance of pelagic species have been unable to define the processes which are at the origin of the ecosystem changes (Caddy and Griffiths, 1990).

As for catches of pelagic fish in the Adriatic, the catches of demersal fish did not increase during the decade 1975-85, the area being already heavily exploited (Caddy and Griffiths, 1990).

The Case of the Gulf of Lion

Freshwater inflow to the Gulf of Lion is mainly by the Rhône. The Ebro, which flows into the southern part of the Gulf, is also important because it can participate in the Gulf's general circulation pattern.

The Ebro and its engineering works

Since the construction of the Aswan Dam on the Nile, the Ebro has become the third most important Mediterranean river in terms of its discharge (Table 1). Its mean discharge (550 m^3/s) accounts for 6 percent of the freshwater runoff entering the Mediterranean (Cid Montanes *et al.*, 1990). The monthly discharges measured at the base of the delta show a maximum in winter (January to March) and a minimum in summer. The maximum floods, recorded further upstream at Zaragoza, have practically never exceeded 3 000-4 000 m^3/s in the last century. The sediment load has decreased by 80 percent since the construction of dams: before, a maximum of 180 $mg.l^{-1}$ was recorded, but nowadays this figure is about 10 $mg.l^{-1}$ (Muñoz and Prat, 1989; Muñoz, 1992) which has slowed the extension of the delta. These authors have also noted an increasing eutrophication of the waters of the lower reaches of the Ebro, near its mouth. In 1986/87 the Ebro transported to the sea 9 to 12 x 10^3 tonnes/year of particulate carbon, 1.2 to 1.4 x 10^3 tonnes/year of particulate nitrogen, 0.3 to 2.0 x 10^3 tonnes/year of particulate phosphorus and 87 to 165 x 10^3 tonnes/year of suspended solids (Muñoz, 1992). There was no correlation between the nutrient content and river discharge. Because of the reduction in riverine inputs of freshwater, a saline wedge is now recorded in the Ebro extending up to 40 kilometres above the river mouth (De Sostoa and Lobon-Cervia, 1989).

Studies have been carried out on the pollutants discharged to the Ebro. For example, Cid Montanes *et al.*, (1990) have estimated that the quantities of organochlorines (HCB, PCBs, DDT) transported, originating from a factory situated upstream, are less than 100 kg/year.

The Rhône and its engineering works

The Rhône is the most extensively managed Mediterranean river. Engineering works were begun in 1934 and were completed in 1980. The initial aims were hydroelectric power production, improved navigation and control of frequently devastating floods. Over its entire course, it is now equipped with 27 dams and 21 hydroelectric generating plants (CNR, 1978). The lowest dam is situated 70 km from the sea.

Extensive canalization was aimed at flood control and improved navigation (canal traffic: 20 x 10^6 tonnes/year). The flooded area decreased from 400 km^2 to 11 km^2 (CNR, 1978). To reduce devastating floods on the former floodplain, many dykes were also built. To improve navigability, dredging works have made the depth uniform and 16 locks have been installed to bypass the dams.

In addition, six nuclear power stations and a radioactive materials reprocessing plant now occur along the river.

The mean discharge at Beaucaire, just above the divarication of the delta distributaries, is 1 710 m^3/s, equivalent to an annual input into the Gulf of Lion of about 50 km^3/year. At the same point, floods in the past could exceed 9 000-10 000 m^3/s and recently (1970-93) instantaneous discharges of greater than 10 000 m^3/s have once more been recorded.

Quantification of inputs by the Rhône

A reduction in the morphological diversity of the managed Rhône has led to a decrease in the biological diversity of the river (Fruget, 1992).

Since the construction of engineering works on the Rhône, the lowest discharges are now recorded in June - July and in November, whereas before management the heaviest discharges occurred from May to September, and were particularly related to Alpine snow melt. Nowadays, the maximum freshwater inputs therefore occur in winter and early spring (December to May). As a result the supply of substances included in agricultural, domestic and industrial effluents is at its maximum, but diluted in winter and early spring, whereas it is at a minimum, but concentrated in summer.

In 1984-85 the suspended solids transported by the river were of the order of 8-196 mg/l (El-Habr and Golterman, 1987). The average discharge of 50 km^3/year from the Rhône therefore causes 26 x 10^5 tonnes/year of suspended solids to enter the Gulf of Lion, mainly in the form of fine silt and clay (El-Habr and Golterman, 1987). Most of these solids will sediment near the river mouth. The quantity of suspended solids discharged by a river (composed of mineral sediments and an organic fraction) plays a dominant role in terms of the productivity of the area receiving this water. For example, the light attenuation in estuaries is mainly a function of the concentration of suspended sediment, so that it is the quantity of suspended solids that limit primary production (Bernard, 1990). The ratio of dissolved to particulate nutrients is low in the Rhône (compared to the Rhine for example). This probably reflects the steeper gradients of the Rhône and therefore a greater erosive power, despite the reservoirs created along its length. Thus, reflecting the fact that the population living in the watershed is much lower, the total nutrient transport of the Rhône is four to five times less than in the case of the Rhine delta (El-Habr and Golterman, 1987). Golterman (1985) also demonstrated an acidification of the waters of the Rhône from upstream to downstream, resulting from mineralization of organic matter, and an accompanying increase in sulphates.

The total quantities of nutrients (including particulate carbon) entering the Gulf of Lion was estimated at 158.6 x 10^3 tonnes/year (El-Habr and Golterman, 1987). In 1984-87, the input of nitrate nitrogen ($N-NO_3$) from the Rhône to the Mediterranean Sea was 7.5 x 10^4 tonnes/year (Denant and Saliot, 1990), i.e., 40 percent higher than the same estimate made in 1968 (Coste, 1974). El-Habr and Golterman (1987) found no correlation between the concentration of dissolved nitrate present in the Gulf of Lion and the discharge of the Rhône. In contrast, there was a strong but negative correlation with dissolved phosphorus and there were strong positive correlations between discharge and suspended solids.

There does not seem to be major impact by nuclear installations on river water, in terms of possible radioactive contamination (Seiller, 1991). During normal operations, these installations can legally discharge low level liquid and gas effluents. For the entire river plant community, artificial radioactivity due to power stations does not exceed 40 percent of its natural background radioactivity, whereas the radioactivity created by fallout from the Chernobyl accident accounted for more than 200 percent of background but was still not dangerous (Seiller, 1991).

Influence of Rhône waters on the Gulf of Lion

The influence of Rhône waters extends over a vast area of the Gulf of Lion and sometimes beyond. It is confined to the continental shelf by the density front which is in dynamic equilibrium with the Ligurian current (Cruzado and Velasquez, 1990). Béthoux *et al.* (1988) have shown that there is a correlation between increases in the rate of flow in the Ligurian current offshore of Nice and coastal inputs of freshwater (coming particularly from the Arno). This type of correlation had already been identified by Bumpus (1973) in the Gulf of Maine and by Royer (1981) in the Alaskan Gulf.

Discharges of freshwater (particularly the Rhône) lead to the waters of the Gulf of Lion and along the French and Spanish coasts being less saline than the surface waters further offshore (Salat and Cruzado, 1981). Loubersac (1976) observed a plume seven nautical miles wide issuing from the Grand Rhône just to the south of the river mouth, initially oriented SSE but then deviated towards the S and SW by the Ligurian current. The Ligurian current extends westward and becomes the Liguro-Provençal current. Then following the change in slope of the coast towards the south, it becomes the Liguro-Provençal-Catalan current (Castellon *et al.*, 1990; Font *et al.*, 1990). To the NE of the Ebro delta, there is permanent coastal upwelling which contributes to the enrichment of the Gulf (Cruzado and Velasquez, 1990).

In summer, the surface concentrations of nutrients (such as nitrates) are low (below 0.4 μg-at. NO3-N/l). In contrast, in winter they are much higher. The discharge of the Rhône leads to the formation of a tongue of brackish water in the eastern part of the Gulf (south of the delta and Marseille), over an area that decreases rapidly with depth (1 100 km^2 at 10 m; 3 300 km^2 at 5 m; 6 000 km^2 at the surface) (Cruzado and Velasquez, 1990). The nutrient concentrations, including those of nitrates, are high over this entire area (1-2 μg-at. NO3-N/l), reaching values of 26-35 μg-at. NO3-N/l near the mouth of the Rhône. The area covered by the brackish water tongue, which also occurs in summer but without high concentration of nutrients, varies in relation to the discharge of the Rhône and with meteorological conditions. Sabatés (1990) reported an abnormal incursion of the plume towards the south in 1983, reaching as far as the northern Catalan coast, due to higher than normal river discharges, which was associated with a superficial thermocline caused by exceptionally sunny weather. High chlorophyll-a levels occurred within the plume, particularly at the marked front where they were three times higher than in other parts of the plume. The structure of the epipelagic fish larva community was affected, the concentrations of larvae being lower in the area covered by the plume. This phenomenon can be explained by the larvae being transported by the plume, leading to higher species and individual abundances at the saline front, either by passive aggregation or because of the high productivity in this area. The species that were rare within the area covered by the plume and concentrated at the front were species occurring preferentially within the surface layers. In contrast, the species counted within the area of the plume were mainly in deeper water, and thus avoided the effects of the plume. In fact it is probable that the species concentrated at the head of the plume consisted of surface-dwelling species only.

These increases in nutrient concentrations, associated with the occurrence of a plume of brackish water, have also been recorded in other parts of the world. For example, Kidd and Sander (1979) revealed that in the case of the discharge of the Amazon, in addition to the low-salinity lenses being richer in silicates than the neighbouring marine waters, it seemed that they led to nutrient enrichment around their margins. Such phenomena could explain the high variability in summer of phosphate concentrations (and salinity) at Barbados (West Indies) corresponding to the passage of these lenses originating from the Amazon or Orinoco. More generally, Dessier (1990) revealed from a literature review, that the water of riverine or estuarine plumes are separated from marine waters by a saline front that is usually very pronounced. Convergence at this front lead to an accumulation of debris and a variety of organisms. Soto *et al.* (1993) studied seasonal changes in communities of microplanktonic within the Rhône plume. They showed that there was a peak in primary producers (phytoplankton and autotrophic flagellates) in spring and a peak of heterotrophic organisms (bacteria and heterotrophic flagellates) in summer. In winter the main primary producers were Cyanobacteria. It is of interest to note that Martin and Saliot (1992) showed that in the northwestern Mediterranean, atmospheric inputs were greater than riverine inputs for various organic and inorganic compounds and elements, for example cadmium (Cd), lead (Pb) and copper (Cu). In contrast, nitrogen seemed to be supplied in equal quantities by rivers and atmospheric inputs.

The wind plays an important role in determining the vertical distribution of salinity and nutrients. Under calm conditions, a layer 2-10 m deep made up almost entirely of freshwater covers a sub-surface layer of sea water. This stratification is destroyed during windy periods. Further south off the Ebro Delta, the nearly permanent and strong winds are not involved significantly in marine circulation, which is always directed towards the south (Font, 1990), except to the extent that they may contribute to increasing existing currents in winter. Cruzado and Velasquez (1990) estimated the primary production of the Gulf to be 120 g C/m^2 per year, of which half is due to the inputs by the Rhône. Diatomaceae account for most of this primary production, followed by dinoflagellates, Coccolithophoridae and Cyanobacteria. Their development takes place mainly at the transitional dilution zone of the plume's waters.

The Fisheries

The difficulties in obtaining reliable fisheries statistics and of reaching a consensus between various authors needs to be stressed. The Gulf of Lion, considered as a relatively isolated ecosystem because of the exceptional extent of the continental shelf and its structure which make it a biogeographical entity, provides 90 percent of the fish landed on the French Mediterranean coasts (7 percent of French production) (Dremière, 1980). About forty species σare exploited, but five of them (sardine, hake, mackerel, poor cod and octopus) account for 60 percent of catches.

Fishing effort has greatly increased in the last 30 years. In 1960 the nominal motor power of the boats used was 10 000 h.p., but this had increased to 53 000 h.p. by 1980. Catches have mirrored this increase: from 7 361 tonnes in 1960 to 28 909 tonnes in 1980 (Oliver, 1983). According to Caddy and Griffiths (1990) French fishery catches in the Gulf of Lion increased by about 2 percent a year in the period 1973-1985. Dremière (1980) considered the increase in yield since 1974 to be probably due to the adoption of more efficient fishing techniques (four-sided trawl nets). Total catches have increased, but these mask a stagnation in catches of demersal fish.

Demersal stocks have in fact been fully, if not overexploited, since 1974-75 (9 450 t caught in 1980, i.e., three times more than in 1960). In the same year, Spanish trawlers produced 2 406 tonnes in the Gulf of Lion with a nominal horsepower of 6 805 h.p., therefore with a much better yield (Oliver, 1983). In 1985 French and Spanish catches were 10 100 tonnes and 4 046 tonnes respectively with nominal horsepowers of 64 000 h.p. and 14 012 h.p..

The sardine accounts for most of the pelagic resources and seems to be underexploited (Oliver, 1983). In Spain, sardine stocks are nearing overexploitation, with the other species being fully exploited. Between 1970 and 1990, sardine catches fluctuated between 12 000 and 22 000 tonnes (Table 2). The anchovy, formerly not heavily exploited by the French, was subjected to increased fishing effort in 1987, leading to catches of 9 500 tonnes in 1989 (followed by a fall in 1990 to about 6 000 t). There is often an inverse correlation between the abundance of anchovies and sardines, possibly because of food competition (Lecompte, 1991). From 1960 to 1980, catches of these two pelagic species increased six-fold.

The influence of rivers on the fisheries

Lecompte (1991) showed that landings of anchovies in the Gulf were correlated with winds occurring in the previous year, and therefore depended on recruitment in that year. In contrast, no correlation was found with the discharge of Rhône. It is practically impossible to demσonstrate any impact, because catches have increased constantly since the 1960s, due at least partly to increased fishing effort. Management of the Rhône therefore occurred at the same time as increased exploitation of the resources. Fishermen were able to adapt to changes in stocks by switching to other species (such as anchovies in France). Perhaps the inputs from the Rhône have remained sufficient to ensure the productivity required for the fisheries. If the increased fishing effort and increase in catches are both taken into account, yields have generally fallen.

Conclusions

A direct relation between river discharge and fishery yields in areas close to the estuary or delta has already been recorded in other regions of the world. There is for example, a strong correlation between river discharge and commercial fish landings in the estuaries of the Mexican Gulf (Day *et al.*, 1985). The same is also true of San Francisco Bay (Rozengurt and Herz, 1985). Sutcliffe (1972, 1973) also found positive correlations between discharge and landings in the Gulf of St Lawrence. Year-to-year variations in runoff can even explain variations between years in fishery production, although the mechanisms are unknown (Sinclair *et al.*, 1986). The mean annual discharge of the St Lawrence River is 424 km^3/year (Sutcliffe *et al.*, 1976), i.e., ten times the mean annual discharge of the Nile before its regulation; its effects therefore extend well beyond the gulf. In the Gulf of Maine,

Table 2
Annual catches (tons) in the Gulf of Lions from 1960 to 1990. Data from IFREMER Sète.

Year	Demersal catches	Pelagic catches	Total
1960	2750	3682	6432
1961	2800	8503	11303
1962	2500	9276	11776
1963	3800	12851	16651
1964	4450	13096	17546
1965	4200	9807	14007
1966	6000	19799	25799
1967	5850	21577	27427
1968	6350	16906	23256
1969	6300	21532	27832
1970	6250	25821	32071
1971	6450	20607	27057
1972	6400	20703	27103
1973	6350	16770	23120
1974	7500	16389	23889
1975	8950	20198	29148
1976	8650	15239	23889
1977	8850	14908	23758
1978	8400	14451	22851
1979	8050	18592	26642
1980	9450	20042	29492
1981	10200	26111	36311
1982	10400	26634	37034
1983	11300	22073	33373
1984	9700	19298	28998
1985	10100	22310	32410
1986	8835	21893	30728
1987	8122	21661	29783
1988	8714	24081	32795
1989	6938	23728	30666
1990	9370	20680	30050
1991	12542	20444	32986

catches of ten species (out of the 15 commercial species) were positively correlated with the discharge of the St Lawrence (Sutcliffe *et al.*, 1977; Drinkwater, 1984), but catches of the four other species were negatively correlated. In the case of the St Lawrence, the regulation of its course has had a major effect, changing the maximum discharge from spring to winter. But the effects of river regulation are always superimposed on natural seasonal and year-to-year variability.

Sutcliffe (1973) nevertheless showed that variability in the discharge of the St Lawrence controlled recruitment of lobster stocks. Sutcliffe *et al.*, (1983) showed that the strength of annual size classes of cod in the Labrador region were correlated with salinity fluctuations. This variability in year class strength was interpreted as being related to fluctuations in nutrient transport, resulting from variable amounts of freshwater flow through the Hudson Straits. In this case, strong flows reduced vertical movements of nutrients, reducing primary production and survival of cod larvae. Sinclair *et al.*, (1986) concluded that, despite higher primary production due to runoff into the St Lawrence Gulf, it was uncertain whether the production of zooplankton, benthos and fish was any greater than in neighbouring areas. Oceanic circulation probably had a greater influence on the fisheries, at least on cod stocks. The impact of regulation of the St Lawrence River, if it exists, is masked by natural variability in discharge and in fish catches.

Govoni *et al.* (1989) showed that fish larvae (ichthyoplankton) are much more abundant in the plume front than outside or inside the plume caused by the Mississippi River. This was later confirmed in the same region by Grimes and Finucane (1991). In the same area, Dragg and Whitlege (1991) showed that concentrations of zooplankton nauplii are generally higher at the plume front than in other areas of the continental shelf, particularly in the summer. This could have important implications for the ichthyoplankton, which is especially abundant in summer. Grimes and Finucane (1991) suggested that accumulation of food (mainly zooplankton and ichthyoplankton) along the Mississippi plume front could be a factor favouring food intake and growth of young fish, and therefore leading to increased survival of these fish. However it remains to be demonstrated, firstly that predation does not cancel these advantages, and secondly that the plume does not cause depletions elsewhere, and that these depletions do not have a significant impact on the adult fishery stocks.

In the Mediterranean, evidence for a relation between inputs of freshwater and fisheries has yet to be demonstrated. As long as the factors (predation, food, etc.) and the mechanisms involved in the survival and spatio-temporal distribution of fish larvae remain poorly understood, it would be illusory to attempt to determine the role of freshwater inputs in the year-to-year variability in recruitment of marine fish species (Legget, 1986; Drinkwater, 1986; Le Direach-Boursier, 1990; Sabates and Maso, 1992).

2. THE IMPACT OF TERRESTRIAL RUNOFF AND FRESHWATER OUTLFOW ON BRACKISH LAGOON FISHERIES ECOSYSTEMS

INTRODUCTION

Coastal lagoons cover ca 650 000 hectares in the Mediterranean, mostly around the western basin (Britton and Crivelli,1993). These are the most biologically productive water bodies in the region, particularly in terms of their fishery yields (Kapetsky, 1984; Crivelli, 1992; Crivelli and Ximenes, 1992).

Because they are more enclosed than coastal waters, lagoons are more sensitive to freshwater inputs and are typified by wide spatial and temporal fluctuations in physical (temperature), chemical (salinity, nutrients) and biological (primary and secondary food chains) properties. As the natural recipients of river catchments, they are the sites where the solid and dissolved matter carried by rivers are stored or sedimented. Management of inland waters must therefore take into account the short-term effects reflected by water quality and the long-term effects of storage in the sediment, itself influencing water quality.

Although salinity is the most important factor to be taken into account in terms of the fish populations, local impacts, such as siltation and changes or disappearance of the aquatic vegetation, and more general impacts, such as stratification, which may restrict the available water volume or changes to communications with the sea, which affects fish migration, can also modify the habitat of some species. Fish have the following fundamental requirements in terms of their natural environment:

(a) factors allowing the species to exist: physicochemical factors such as temperature, salinity, oxygen and habitat factors such as substrate for benthic species. In the case of coastal lagoons, the ability to colonize the habitat must be added for some marine species;

(b) trophic factors: adequate food resources for each species and development stage (size and type of prey); and

(c) factors allowing reproduction.

It is useful to classify the species occurring in coastal lagoons into groups sharing similar responses to the freshwater/sea water gradient. Three categories can be defined:

- the so-called "freshwater" species, which include species inhabiting the lower reaches of rivers and which can survive in the lagoon if the salinity remains low (less than 10 g/l for the most tolerant). These include Cyprinidae (carp, rudd, roach) and the zander. Coastal lagoons are frequently important spawning and nursery areas for these species, since the rivers usually enter the lagoons in shallow silted zones suitable for the development of beds of submerged vegetation (spawning substrates) and having warm water;

- the so-called "sedentary" species, which are euryhaline lagoon or coastal species, capable of breeding either in the sea or in the lagoon. Of small size and having a short life span (three to four years), they include *Sygnathus*, small Gobiidae, *Gambusia*, *Aphanius* and *Atherina*, only the latter having any commercial value. The key factor for the development of these species is the presence of well-developed submerged vegetation (spawning substrate favourable to fry survival). *Atherina* declines at the expense of *Aphanius* and *Gambusia* when there is excessive invasion by submerged vegetation or when reedbeds become abundant. The conditions that are unfavourable for the development of the exploitable sedentary species (Atherina) are therefore shallowness (complete invasion by submerged vegetation) and general lowering of salinity in the water body (favouring reedbeds). These species serve as forage fish, particularly for sea bass and eels;

- the so-called "migrant" species which spawn in the sea, then spend part of their development in a lagoon with successive migrations between the two. Most of the commercially valuable species are in this category (Sparidae, sea bass, Soleidae, red and grey mullets, eel, cephalopods, shrimps, prawns, etc.). The most important factor affecting these species is the communication with the sea, of which the most sophisticated management is practised in Italy in lagoons known as vallis. Knowledge of the migration habits of the species is essential. Migration timetables are available (Figure 2; Cambrony, 1984; Chauvet 1986) and it is useful to distinguish between the active migration stages, where movements take place against the current, and periods of passive transport (Chauvet, 1986; Bourquard, 1985). The current speed in the channels connecting the lagoons to the sea, which to some extent depends on the quantity of freshwater supply, is also of importance (Bourquard, 1985). The second most important factor is salinity. Tolerance of low or high salinities varies between species.

State of the Fisheries

Lagoons account for 3 percent of fishery catches in the Mediterranean (including freshwater, brackish and marine fisheries), i.e., 50 000 tonnes per year (1978-1987), (Crivelli, 1992). Fish are mainly caught in the lagoons of Greece, Italy, France and Tunisia. A median yield of 56 $kg.ha^{-1}{}_{y}{}^{-1}$ with a range from 5 to 689 $kg.ha^{-1}{}_{y}{}^{-1}$ has been calculated for 125 Mediterranean lagoons (Crivelli, 1992). Kapetsky (1984) cited a median yield of 51 $kg.ha^{-1}{}_{y}{}^{-1}$ for 107 lagoons around the world. Aquaculture and oyster and mussel farming have increased greatly, probably in relation to lagoon enrichment, either from coastal waters or coastal runoff. Depending on the region and the method used, intensive aquaculture and especially suspended mussel culture (Ceccherelli and Barboni, 1983) can give high yields : 10-50 tonnes/ha/year. This technique has led to production increasing by about 22 percent per year, from 12 000 tonnes in 1975 to 92 000 tonnes in 1986. Bivalve production on the sea floor in the sublittoral or intertidal zone produces lower yields: 5-10 t/ha/year (Caddy and Griffiths, 1990).

There are two categories of lagoon fishery:

- fishing within the lagoon with nets, which is limited by excessively deep or shallow water and by invasion by vegetation,

- fishing at the connecting channels with fixed fish traps, which can be hindered by siltation and may become impossible if the current is too strong.

In France, fishing (within the lagoon with fyke nets) is most intensive in shallow lagoons (Ximenes, unpublished data), probably because the entire area is available for fishing. A seasonal analysis shows high activity in autumn, concentrated in areas communicating with the marine environment (return of migrant species to the sea) and a spring and summer activity in areas under the influence of freshwater inflows.

Socio-economic aspects also need to be taken into account. Depending on the country and the region, some species are more appreciated than others: e.g., Mugilidae are much taken in North Africa and Greece, but little appreciated in France and Italy.

The marketing structures also largely determine the economic value of the resources. For example, migrant species have a high market value around the Mediterranean and have a diffuse and short marketing circuit. All these fish are sold without difficulty. In contrast, the eel is marketed mainly through organized and specialized networks. The timing and location of landings of this species are strongly dependent on the presence and activity of fish wholesalers. For example the absence of such "middlemen" in Algeria has led to a sporadic exploitation within Lake Mellah, with exportation to Italy; whereas, in contrast, the presence of several wholesale companies in Languedoc-Roussillon (southern France) allows this species to be exploited throughout the year.

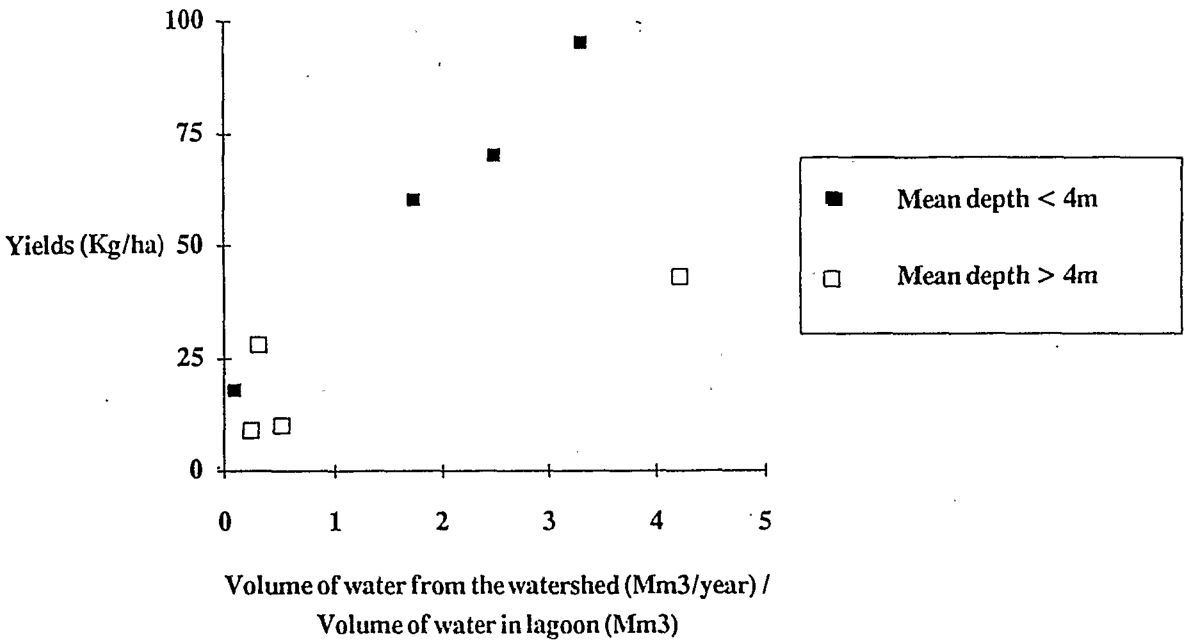

Figure 2. Relation between eel fishery yield and freshwater inputs to French coastal lagoons (Ximenes, unpublished data).

The management of the watersheds of Mediterranean lagoons

A change in the salinity of a lagoon, is therefore reflected in economic terms by potential gains or losses.

The salinity is dependent both on the quantities of water provided by the watershed and also by marine inputs. The effect of salinity can be illustrated by some examples of French lagoons where an increase in salinity (Etang du Vaccarès: 4-8 g/l from 1952 to 1979 and 20 to 30 g/l from 1982 to 1989; Heurteaux, 1992) or a fall in salinity (Etang de Berre: 30-32 g/l before 1966 to 10-15 g/l after 1966; Schachter, 1954; Le Corre and Garcia, 1989), led to a change in the number of species in the migrant and freshwater groups, with in general a maintenance of the total number of species of fish, but a decrease in benthic diversity (Stora and Arnoux, 1983; Crivelli and Ximenes, 1992).

Inputs from the watershed can be quantified in various ways (volume of water, suspended solids input, nutrient input, input of chemical pollutants). The impact of each of these factors needs to be examined separately.

Volume of water input

The first impact is physical. The change in water level, which is more pronounced in sites where communications with the sea are absent or reduced, in extreme cases can lead to alternate periods of flooding and drying out by evaporation. The succession of dry and flooded periods leads to mineralization of the sediments (in dry periods) favouring primary production on reflooding (mineral salts are immediately available) and providing favourable conditions for benthic species.

Depending on the nature of the surrounding land and the water table, the salinity may increase greatly during the period of evaporation, leading to death of the macroflora and macrofauna. Most coastal lagoons have low, gently sloping shorelines, so that increased input of water leads to flooding of marginal areas, which dry out gradually. The management of freshwaters in these areas determines the type of helophyte and hydrophyte plant community, whose importance as spawning and nursery areas and for the survival of sedentary species was mentioned above.

An increase in freshwater inputs leads to an increase in discharge of low-salinity water towards the sea and increased current speeds in the connecting channels. In some lagoons, where there is no permanent connection with the sea, increased inputs of freshwater can lead to build up of a head of water in the lagoon and rupture of the sand bar, forcing a passage to the sea. If it is desirable to artificially increase the inputs of freshwater to a lagoon it is essential to adapt the seasonal timing and the effects on the currents in the connecting channels with the migration patterns and behaviour of fish, and if need be, to install special equipment in the channels to avoid excessively fast currents.

The second type of impact is chemical in nature, involving a change in the salinity. The predicted spatio-temporal variation in salinity must be examined in relation to the requirements of the non-euryhaline species (mainly the freshwater and migrant species). Particular attention must be paid in Mediterranean lagoons to increased salinity in summer due to intense evaporation during this season. Finally, for the eel, which is a migratory species in terms of spawning, but which only make a single migration towards the sea in its lifetime, recruitment is improved, the greater the "call of freshwater" between November and March. This is an undemanding euryhaline species. The yields of this species, which is heavily exploited in French Mediterranean lagoons, increase greatly in shallow lagoons with increased quantities of water supplied by the watershed (Figure 3). In deep lagoons (e.g. Etang de Berre) increased inputs of freshwater lead to stratification and anoxic conditions in the hypolimnion, making most of the lagoon unproductive. Raising the trophic status also leads to an increased fishery yield, but increased trophic conditions can also lead to anoxia and massive fish kills due to decomposition of excessive macro- or phytoplanktonic algal growth, following which the fish population may be unable to rebuild itself (Bouchereau *et al.*, 1990).

Suspended solids

Inputs of suspended solids originating from terrestrial runoff contribute to siltation of coastal lagoons (Figure 4), leading to:

- reduced overall depth in the water body,
- the formation of a sediment fan at the mouth of the river with the progressive advance of the land area of the delta,
- inputs of fine particulate matter that is transported to deep water areas.

Reduced depth favours the development of rooted aquatic vegetation, which itself serves as a sediment trap and produces additional autochthonous organic and inorganic (calcium carbonate and silicate) sediments, especially in the case of reedbeds.

The quantity of suspended solids provided by the watershed depends on the slope, the soil type, the land use and the rainfall. These four variables can be used to compute a preliminary specific erosion factor, that has been evaluated for French Mediterranean watersheds at 175 tonnes/km^2, or 410 m^3 of silt/km^2 (LCHF, 1978 in SMNLR, 1991). The suspended solids load is heavier in floods; flood overspills into lagoons thus favour siltation. The suspended solids load entering a lagoon increases when dyke construction works are carried out upstream, by increasing erosion and preventing flooding and siltation on the former floodplain.

Nutrient inputs

Nutrient inputs include organic matter, nitrogen, phosphorus and in the case of lagoons with a salinity close to that of sea water and where this element is often limiting, iron.

In semi-enclosed lagoon environments, where accumulation frequently occurs, their impact may lead to a progressive increase in trophic status. The inorganic forms of nitrogen and phosphorus are immediately available for primary production by phytoplankton and macrophytes, whereas organic forms must first be decomposed by bacteria, which consume oxygen. Overall, these processes contribute to activating all trophic pathways (both primary and secondary production), this production being only partly exported and therefore accumulating in the sediments (Sfriso *et al.*, 1992, 1993).

The accumulation of organic matter leads to a tendency for anoxia in the sediments (even in shallow lagoons), that is more pronounced in warm, calm weather. This leads to the possibility of contamination of the entire water column (summer anoxia events), that in turn can lead to massive fish kills of both natural and farmed populations. In shallow lagoons, the disappearance of angiosperms and their replacement by Rhodophyceae and Chlorophyceae is more prevalent when nutrient inputs from the watershed increase. It is therefore essential that the effects of water management on plant populations in terms of production within a site be taken into account.

Increased inputs of phosphorus by the watershed produce an irreversible increase in sediment concentrations (Lieutaud *et al.*, 1992), generally with a more pronounced accumulation in the areas of the lagoon receiving the inputs (Casellas *et al.*, 1990).

In the case of nitrogen, the relation between inputs and stocks is more complex because of the geochemical recycling of this element (subterranean and atmospheric inputs, in situ nitrogen fixation and losses by denitrification).

For a lagoon, the sum of all inputs must be taken into account, distinguishing between:

- nitrates of agricultural origin entering in the surface runoff and in the groundwater

- ammonia and phosphates from domestic sewage and industrial effluents entering in the surface runoff.

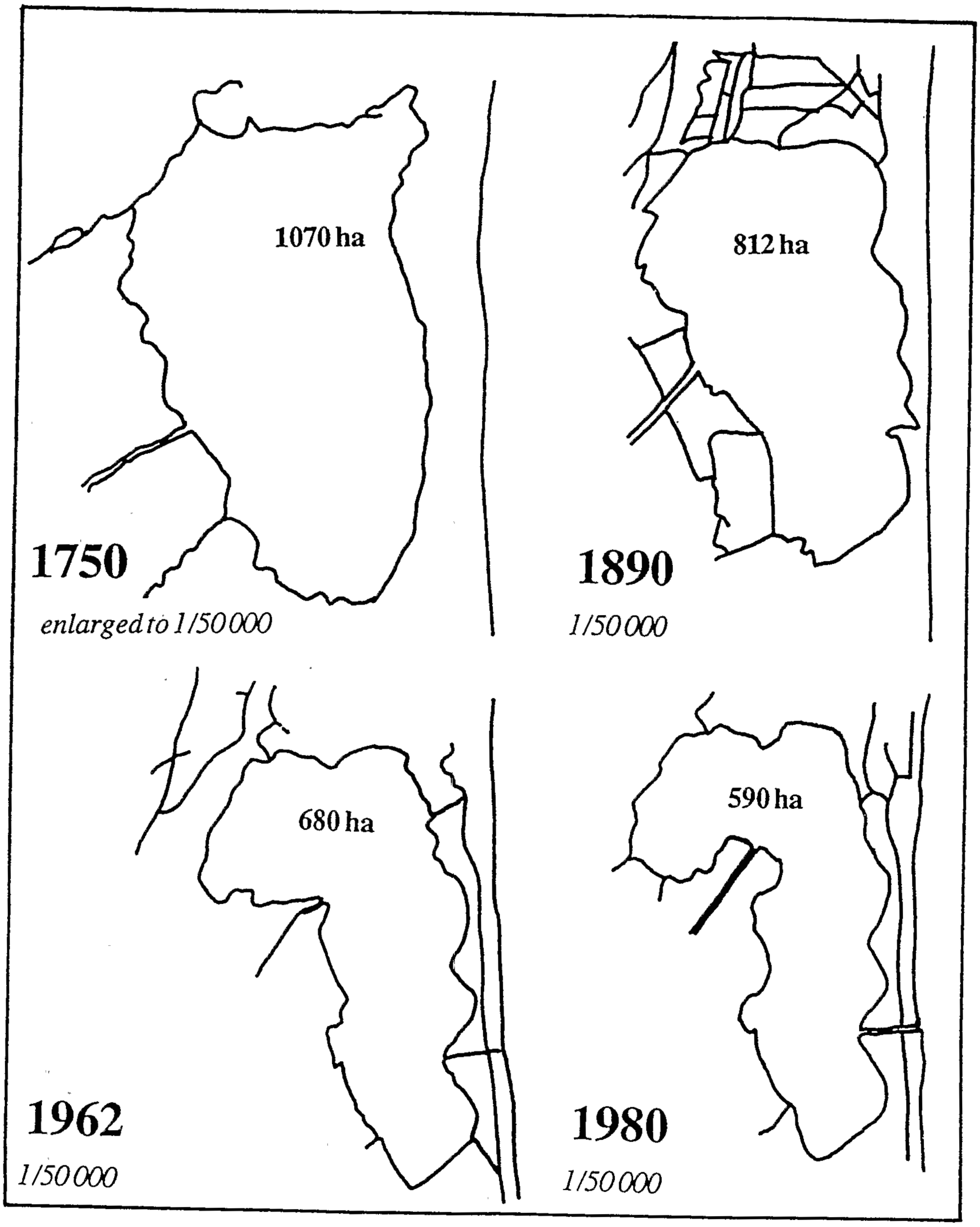

Figure 3. Siltation processes in a coastal lagoon, Etang de Canet, southern France (in SMNLR, 1990)

However, in practice these distinctions are blurred, since most ammonia in sewage is oxidized to nitrate in the treatment works or in the receiving river before it reaches the lagoon, and some phosphorus is undoubtedly of agricultural origin, from NPK fertilizers or from animal excrement.

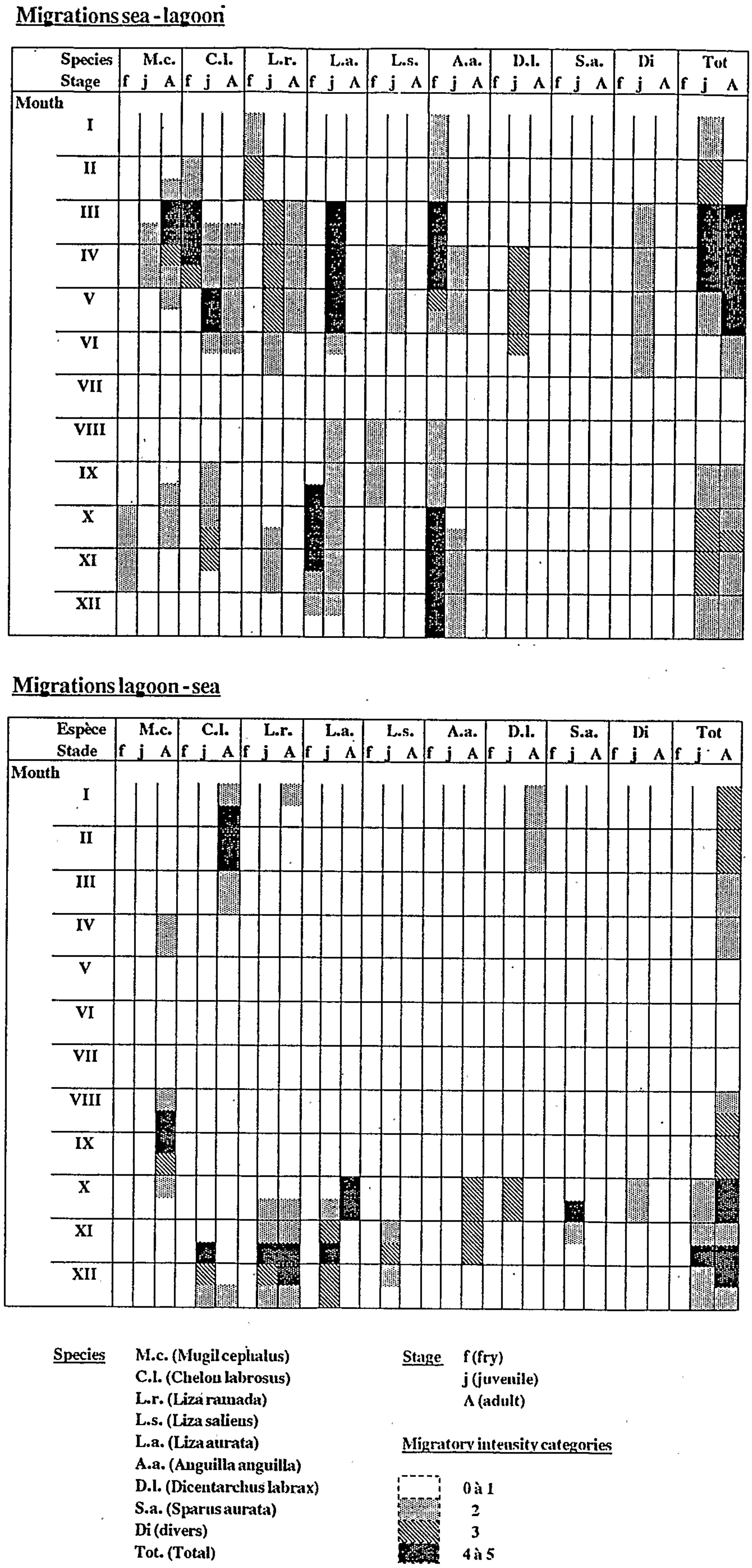

Figure 4. Timing of fish migratory movements (Chauvet, 1986)

Management of the waters of a watershed must take into account:

- runoff from natural and agricultural land, which is increased by scrub clearance, by bare soils or by cultivation at right angles to the contours;

  (Crops, such as market garden produce and rice, that require large quantities of fertilizer, provide the largest nitrate inputs and should not be grown near lagoons);

- urban inputs, whose direct discharge to a lagoon provoke irreversible enrichment of the sediments with phosphorus. At present some eutrophicated coastal lagoons (Lac de Tunis, Laguno di Orbetello) have been partially rehabilitated by stopping all discharge of urban effluents.

  (Some mollusc-eating Sparidae (e.g. gilt-head bream) disappear if the sediments become enriched with organic matter, which leads to a decline in prey abundance).

Warm water inputs

Chauvet (1986), examined the impact of discharges of cooling water from fossil fuel power stations into the Lac de Tunis and showed that 15 tonnes of fish were killed each year by a discharge of 6 m^3/s. Mortality resulted from decreased oxygen concentrations in the water because of increased lake temperatures, from discharges of chlorides and antifouling products, and from an increased incidence of parasitic diseases.

These harmful effects were recorded, in contradiction to forecasts, at a latitude where natural temperatures reach high levels.

The same author recommended that power stations on lagoon shores should be designed so that cooling is pumped from the lagoon, but is discharged to the outflow or to the sea, if possible at a site that favours the entry of fish into the lagoon.

Chemical pollutants

Péna and Picot (1991) give a table of the mean concentrations of micropollutants in the sediments of various Mediterranean ecosystems, including several lagoons. These inputs originate from domestic, industrial and agricultural sources. In some cases, the degree of contamination could become alarming. Excessively high inputs of various pollutants could result in toxicity to lagoon species (shellfish and fish farms) and decreases in biological diversity.

Conclusions

Terrestrial inputs and inputs of water originating from the watersheds of Mediterranean lagoon systems threaten the continued integrity of these systems by accelerating siltation and degrading their biological production. The area of lagoons in the Languedoc-Roussillon (southern France) has declined from 33 000 ha in the 18th century to 26 000 ha in 1990 (SMNLR, 1991; Barusseau *et al.*, 1992). Siltation of the remaining lagoons is not inevitable, provided that measures are taken quickly. These would involve: stopping all drainage which is prohibited by the law, better management of the watersheds, by land restoration, by prohibiting dyke construction and gravel extraction along rivers and by opening the channels to the sea more frequently. A reduction in the use of fertilizers in agriculture and sewage treatment would also contribute to reducing siltation of these lagoons. All these improvements would at the same time improve eutrophication problems in lagoons and reduce anoxic events which are the most harmful effects.

3. GENERAL CONCLUSIONS

In the last few decades, the increase in the concentration and diversity of pollutants of domestic, industrial and agricultural origin, draining from watersheds via rivers towards the sea has aggravated the natural disturbances resulting from inputs of freshwater in the coastal marine environment and lagoon ecosystems. Since the 196Os, a sharp increase in the human population living either permanently or seasonally around the shores of the Mediterranean has provoked an additional input of poor-quality freshwater that is discharged directly to the sea, a cause of destruction of the coastal marine environment. Finally, constantly increasing water extraction from watersheds for domestic, industrial and agricultural use has considerably reduced freshwater inputs to the marine environment.

As inputs of freshwater are one of the main causes of natural disturbances to the marine and lagoon environment, all these events affect ecological conditions in the marine environment. Outside of lagoons, inputs of freshwater mainly affect the sublittoral zone, which receives and integrates the main shock; the coastal environment can therefore be defined as an interface environment, subjected to many terrestrial influences. The integration of these terrestrial influences make the sublittoral zone a very enriched (eutrophic) one compared to oceanic waters and therefore particularly productive.

In the Mediterranean, where tidal currents are weak, the surface circulation of waters is mainly controlled by the wind, particularly in the littoral zone, whereas the major deep-water circulation in the Mediterranean (e.g. the Ligurian current) is driven by internal pressure forces.

Although the impact of these changes on the phytoplankton is fairly well understood, much less is known about the zooplankton and there are enormous difficulties in discerning any possible effects on the fish populations of lagoons, coastal and offshore waters. This is mainly due to the fact that:

(a) only catches of commercial species have been reliably monitored in the long term and can be correlated directly or indirectly with qualitative and quantitative changes in the various inputs. Unfortunately there has been an intensification in fishing effort over the same period which prevents any understanding of the interactions between these variables;

(b) our understanding of the factors controlling the survival of marine and lagoon fish in their larval state, a key life stage for determining the abundance of stocks of adult fish, is still fragmentary. This again prevents any conclusions from being drawn concerning possible impact on marine and lagoon ecosystems of the changes that have occurred in terrestrial and freshwater inputs.

In the future it is likely that the quality of water discharged into the sea or lagoons will improve (e.g. due to treatment of domestic and industrial effluents), but on the other hand, the quantities of freshwater brought down by the major rivers and smaller coastal rivers are liable to continue decreasing. The freshwater requirements in the Mediterranean region are constantly rising and already several coastal cities (e.g. Athens and Barcelona) suffer from chronic water shortages. Some countries already use their entire water resources (e.g. Libya, Israel, etc.). Added to this, there is increasingly frequent overfishing of a large number of fish species in the Mediterranean, so it is difficult to be optimistic about the future of fish stocks.

It is essential that managers of hydrographic systems in Mediterranean countries take better account, in their management plans for watersheds, of the quality and quantity of water that actually enters the sea or lagoon. For their part, scientists must start studies of non-commercial species, not subjected to professional fishing, in order to obtain a better understanding of the impacts of terrestrial and freshwater inputs of freshwater on marine and lagoon fish species, instead of always studying commercial species of fish. Only long-term multidisciplinary studies (hydrology, physics, biology, etc.) can provide answers to the many questions that are posed by the effects of terrestrial runoff and riverine outflow of freshwater on lagoon and marine environments.

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