FISH MASS MORTALITY IN THE ETOLIKON LAGOON, GREECE: THE ROLE OF LOCAL GEOLOGY

by

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ABSTRACT. - Mass mortalities of fish in the Etolikon lagoon have been observed sporadically. In the mass mortality which occurred in November 1990 it has been estimated that a large part of the fish stock was lost. As a result, fish catches were greatly reduced in the lagoon in the following years. Hydrobiological studies suggest that the deaths are due to the high concentration of H_2S in the hypolimnion. The continual enrichment of the water with H_2S is attributed to the presence of gypsum deposits in the drainage basin and to the anaerobic breakdown of the accumulated organic matter. The presence of H_2S in combination with the physiography of the ecosystem, the influxes of fresh and salt water, the runoff of agricultural chemicals and the strong prevailing southerly winds are responsible for the observed phenomenon.

RÉSUMÉ. - Mortalités de masse de poissons dans la lagune d'Etolikon, Grèce: le rôle de la géologie locale.

Des mortalités de masse de poissons ont été observées de façon sporadique dans la lagune d'Etolikon. Une grande partie du stock de poissons a été considérée comme perdue après celle qui est survenue en novembre 1990. En conséquence, les captures de poissons dans la lagune ont été considérablement réduites pendant les années suivantes. Des études hydrobiologiques suggèrent que ces mortalités sont dues à une forte concentration de H₂S dans l'hypolimnion. L'enrichissement permanent de l'eau en H₂S est attribué à la présence de dépôts de gypse dans le bassin versant et à une période anaérobique causée par l'accumulation de matière organique. La présence de H₂S combiné avec la physiographie de l'écosystème, l'afflux d'eau douce et d'eau salée, le recours aux engrais agricoles et la prédominance des vents de secteur sud expliquent ce phénomène.

Key-words. - Fish population, Greece, Lagoon, Mass mortality.

The Mesolongi and Etolikon lagoons $(38^{\circ}18'36''N-21^{\circ}32'00''E)$ in Western Greece are among the largest lagoonal ecosystems in the Mediterranean (Fig. 1). The Etolikon lagoon with a surface area of 16 km^2 makes up the northern part of the ecosystem, while the Mesolongi lagoon with a surface area of 110 km^2 comprises the central and southern part. The Mesolongi lagoon is connected to the south through sandbanks to the Gulf of Patras (Fig. 1). The lagoons themselves are connected by two narrow openings, with a length of 50 m and depth of 0.5 m, which occur on either side of the Etolikon Island. The Etolikon lagoon is a meromictic lagoon with a mean depth of 12 m and maximum depth of 30 m. It has an atypical orientation and is a tectonically formed lagoon (Hatzikakidis, 1952; Day *et al.*, 1989; Danielidis, 1991). The Mesolongi lagoon is shallow (mean depth 0.5 m; maximum 1 m) and lies with its long axis parallel to the shore line and is a typical lagoon (Day *et al.*, 1989; Danielidis, 1991). The Acheloos and

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Fig. 1. - Map of the Mesolongi and Etolikon Lagoons. The arrow head indicates the point where the slick appeared, which is also the deepest point of the lagoon.

Evinos rivers, have also participated in the formation of the lagoons through the deposition of sediment.

DESCRIPTION OF THE EVENT

In the second week of November 1990, severe southerly winds were encountered in Western Greece, which caused flooding and damage in the region. When the bad weather stopped, a smell of « bad eggs » was noted in the early hours of 16th November 1990, which during the course of the day became stronger and by the end of the day was unbearable. Early in the afternoon a large yellow-green slick appeared on the surface water in the north-western part of the Etolikon lagoon, which continued to spread towards the periphery. Flocks of birds were observed on the surface of the water feeding, while schools of fish which had reached the shore were gulping at the surface of the water in an attempt to obtain oxygen. A large number of fish were observed at the shore, at the point where the waves were breaking, with their backs almost entirely out of the water. During the days that followed, dead fish covered the length of the shore and the smell was unbearable.

By the end of the first day, the concentration of dissolved oxygen in the water was 0 mg/l (Fig. 2) and it remained close to zero over the next three days. On the fourth day and thereafter, there was a gradual increase in dissolved oxygen. A dark-coloured precipi-



Fig. 2. - Concentration of dissolved oxygen 30 cm below the surface of the water. A. For the period 16th - 29th November 1990. B. For the period June 1989 until December 1990. Sampling was carried out on the last day of each month, for the period May 1989 - December 1990.

tate covered the bottom of the lagoon which was probably iron monosulphide, FeS (Koutsoukos, pers. comm.). It appears that the dissolved oxygen was consumed in oxidative processes occurring in the lagoon. When these stopped the lagoon began to reoxygenate. Fifteen days later, the dissolved oxygen concentration was 2.9 and 3.4 mg/l at a distance of 500 m and 3 km from the point where the slick appeared.

The mean width of the dead fish zone, along the length of the shore, was 3 m. In order to estimate the number of dead fish cast up on the shore, the density of fish at five sites was calculated, according to the method of Economidis and Vogiatzis (1992). The mean number of fish per square metre was 7.18. The lagoon has a perimeter of 14.2 km,

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therefore the total number of dead fish along the length of the shoreline was estimated to be 305,870. The mean fish weight was 150 g, therefore the total weight of dead fish was about 45.9 tonnes. This calculation does not take into account dead fish which sank to the bottom of the lagoon. From the values of mean annual fish catches by traditional fishing methods (stationary entrapping systems) in the lagoon, it was found that in 1990 catches were reduced by 137.2 tonnes. Therefore, by subtracting the estimated tonnage of fish which was washed up on the shore (45.9 tonnes) from this value it can be concluded that almost twice as many fish (91.3 tonnes) remained on the bottom of the lagoon.

Most of the dead fish were Mugilidae (mullets) ranging 50-400 g in weight, with a small number of *Dicentrarchus labrax* (seabass) ranging 200-1500 g in weight. Almost few eels and gobies were found on the shore. These species live mainly on the lagoon bottom and have narrow gill openings. It appears that most of the dead fish remained on the lagoon bottom, since the species composition of dead fish on the shore was significantly different from that determined earlier from fish catches in the lagoon (Panagiotopoulos, 1916; Dimitriou *et al.*, 1994). In addition, local fishermen reported that for a long time after the event, that their nets were filled with fish skeletons. In the Etolikon lagoon 20 species of fish can be found 4 Mugilidae (*Chelon labrosus, Liza aurata, Liza saliens, Mugil cephalus*), 4 Gobiidae (*Gobius cruentatus, Gobius niger, Gobius paganellus, Zosterisessor ophiocephalus*), Anguilla anguilla, Atherina boyeri, Aphanius fasciatus, Belone belone, Blennius ocellaris, Dicentrarchus labrax, Engraulis encrasicolus, Gambusia affinis, Sardina pilchardus, Sparus aurata, Syngnathus abaster, Symphodus tinca (Economidis, 1973; Leonardos, 1996).

The dead fish had their mouths open and their gillcovers were extended, which is indicative that the fish died from asphyxiation (Moller and Anders, 1986). Almost all of the seabass examined also had their fins extended. The examination of half-dead seabass showed that there was a slight decolourisation of the gills and that the livers had a yellowish colour and were easily broken into pieces. Toxicological tests indicated that the fish deaths were not due to infections or toxic factors.

DISCUSSION

Due to the shape and the way in which the Etolikon lagoon was formed a permanent thermocline and halocline exists throughout the year which according to Danielidis (1991) occurs between 15 and 20 m. Although the surface layers of the lagoon are well oxygenated, the deeper regions are anoxic. At depths greater than 10 m, the dissolved oxygen concentration is zero and the concentration of hydrogen sulphide increases continuously (Hatzikakidis, 1952; Danielidis, 1991).

Towns and highly cultivated agricultural areas in the vicinity of the lagoon produce an influx of sewage and irrigation run-off rich in nutrients. The influx of nutrients causes an increase in primary productivity but also a high oxygen demand during decomposition of the organic mater (Avramidou and Koutsoukos, 1990). In addition, large gypsum (CaSO₄ 2H₂O) deposits to the north-west of the Etolikon lagoon generate hydrogen sulphide in the hypolimnion (gypsum dissolves in water to produce sulphate ions (SO₄⁻²), which under anaerobic conditions are reduced to elemental sulphur and hydrogen sulphide). The organic and inorganic material rich in sulphur compounds is broken down by bacteria present on the lagoon bottom producing sulphides. The bacteria under anaerobic conditions use sulphur as an electron acceptor with the reduction of sulphur to S⁻², HS⁻

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and H_2S . These sulphur compounds are either oxidised to elemental sulphur or remain as hydrogen sulphide (Widdel and Pfennig, 1984; Das, 1989; Day *et al.*, 1989). Hydrogen sulphide can either be oxidised to elemental sulphur by sulphur-bacteria, or be released into the surrounding water (Goldman and Horne, 1983) or reacting with Fe to produce iron sulphides which are very stable in anoxic pure water. Gases produced by anaerobic processes, mainly H_2S , are trapped by the permanent thermocline and halocline in the hypolimnion (Riera and Abella, 1991). The limited renewal of water in the lagoon, which is due to the narrow parts of connection between the Etolikon and Mesolongi lagoon, aids the stratification of the water column.

The anoxic nature of the deep water and the absence of sunlight (Danielidis, 1991) create favourable conditions for anaerobic processes to occur and high concentrations of hydrogen sulphide are observed in the depths. According to Hatzikakidis (1952) hydrogen sulphide concentrations increase with depth from 0.5 mg/l at 10 m to 28 mg/l on the lagoon bottom. They also report that sulphur bacteria, mainly representatives of the species *Beggiatoa*, are present in the deepest parts of the Etolikon lagoon.

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The strong southerly winds which occur in autumn or early winter cause mixing of the deeper lagoon water with surface water, causing fish mass mortalities. According to Paperna and Overstreet (1981) the hydrogen sulphide of the hypolimnion is liberated usually after strong winds, a fact which is ascertained each time fish mortalities are observed in the Etolikon lagoon. Moller and Anders (1986) report that in many cases it is impossible to distinguish if the deaths are due to the absence of oxygen or the presence of hydrogen sulphide. Hydrogen sulphide is extremely toxic to fish and the maximum acceptable concentration of undissociated hydrogen sulphide is 0.002 mg/l (Roberts, 1978).

According to Sinderman (1990) the term «mass mortality» refers to an event which is catastrophic, relatively sudden and of short duration. Mass mortalities in the Etolikon lagoon were first recorded in 1881 and have been observed several times since notably in 1963, 1992, 1995 (pers. obs. and depositions by local inhabitants). With the onset of the phenomenon a number of fish escaped towards the Mesolongi lagoon, while most of those which did not manage to escape were trapped and died. It was found that only Aphanius fasciatus survived. This is a small fish especially tolerant of low concentrations of dissolved oxygen. Gambusia affinis was found in places with influxes of fresh water. A few, mainly small, Mugilidae were also found at places where the two lagoons are connected, in the days following the event. During the last ten years, similar events on a small scale have occurred with ever increasing frequency. The production of H₂S is always a direct result of biological processes. The abiotic factors involved are the rate of input of dissolved sulphate and the availability of wind energy to overturn the toxic bottom water. Man's influence on the process may have caused the increased incidence of fish mass mortalities, but equally this could be a direct result of climatic change, producing more of the winds required to cause overturn, or more rain in winter to dissolve sulphate.

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