Are the Mediterranean Waters Becoming Warmer? Information from Biological Indicators

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The authors are biologists specializing in benthos or ichthyofauna survey. They have worked in marine protected areas or in other littoral zones of the Mediterranean Sea for a long time. The use of SCUBA diving as a sampling method allows them a great knowledge of the benthos and ichthyofauna. Charles-François Boudouresque is vice-chairman of the Benthos Committee of the CIESM, and chairman of the scientific committees of the National Park of Port-Cros and of the Natural Regional Park of Corsica (marine reserve of Scandola). The other authors are members of these scientific committees.

Important changes described in the marine littoral zones throughout the world are attributed to short term phenomena such as marine pollution. Recently, a few authors have emphasized medium to long-term modifications of the ocean conditions (Mearns, 1988). Increasing concentrations of carbon dioxide and other infrared absorbing gases are widely proposed as a mechanism of global surface warming over the next several decades (Ausubel, 1983). Over the past 20–30 years, a significant increase in the average temperature of the waters of the western Mediterranean basin has been observed: between 1973 and 1987, an increase of 0.4°C at 80 m depth (Pascal, pers. comm.), and between 1959 and 1989, an increase of 0.12°C under 400 m (Bethoux et al., 1990). Similar observations have been made in the other ocean basins (Bindoff & Church, 1992). In view of our present-day knowledge of the shallow waters of the Mediterranean, we can only put forward a model-based assumption of temperature increase (Bethoux et al., 1990). Winds, currents and albedo can strongly induce variations of the surface temperature (Ivanoff, 1972) but physical measurements cannot demonstrate a significant mean temperature increase at present, even if it exists. However, the possibility of an increase is suggested by the marine flora and fauna which integrate medium-term changes in ambient conditions (Soule & Keppel, 1988). Unusual occurrences in marine life may also be used as indicators of changing ocean conditions (Mearns, 1988).

In the following analysis, we have only considered those species having well-established preferences in terms of temperature (thermophilic or not). Data were obtained from three geographical zones where scientific observation has been continuous over several decades, in order to minimize the bias resulting from sampling irregularity: Port-Cros National Park (Var, France), Natural Reserve of Scandola (Corsica) and Golfe du Lion (Fig. 1). Data on other zones are also available, but we have chosen not to include them because observation periods have not been as constant and/or because there is a shortage of past comparative data.

In Corsica, at Scandola, the frequency of two species of algae has increased in shallow waters (3–6 m depth) from 1989 to 1992: Dasycladus vermicularis (% occurrence in 400 cm² quadrats: 1 in 1989, 20 in 1992), Digena simplex (% occurrence: 0 in 1989, 10 in 1992). Both species, absent in the coldest zones of the Mediterranean, particularly in the Golfe du Lion, are considered to be thermophilic (Feldman, 1938; Cinelli, 1979). Simultaneously, two other less thermophilic
species, present throughout the Mediterranean and as far up as Brittany in the Atlantic, have regressed strongly: *Halopithys incurvus* (% occurrence: 73 in 1989, 37 in 1992) and *Sycocaulon scoparium* (% occurrence: 24 in 1989, 12 in 1992).

Over the past 10 years, we have observed that several Echinodermata species, considered as thermophilic, are increasingly abundant in the western Mediterranean waters. At Scandola, between 1983 and 1992, the abundance of the Echinidea *Arbacia lixula*, considered as thermophilic (Kempf, 1962) has multiplied by more than 10 (Table 1). The Echinidea *Centrostephanus longispinus*, other thermophilic species (Gamulin-Brida & Span, 1980), long scarce in north-western Mediterranean waters, is now abundant in Port-Cros (Francour, 1989). The recruitment of this species is very scarce in the north-western Mediterranean (Francour, 1991) and it has been observed for the first time at Scandola in 1991. *Ophiidiaster ophidianus*, a thermophilic Asteroidea (Tortoneze, 1957), was observed for the first time in the reserve of Scandola in 1990. Its presence had never been reported here or in other Corsican waters before.

We have observed recently in Port-Cros, Scandola and in the Golfe du Lion several fish species that are now common in the eastern Mediterranean, the warmest zone of this sea (Ivanoff, 1972). *Thalassoma pavo*, a Labridae abundant in the eastern Mediterranean, has always been scarce or exceptionally present in the north-western basin (Whitehead et al., 1984–1986). Its arrival in Scandola dates specifically back to 1988. Since then, its density has increased by a factor of 10 (Table 1) and juveniles have been observed since March 1991. In the waters of Port-Cros, the presence of this species probably dates back further (Francour & Harmelin, 1988), but in smaller numbers. Its population has clearly increased since 1988, and an important recruitment was noted for the first time in 1992. We observed *Thalassoma pavo* for the first time in 1990 in the Golfe du Lion, the coldest zone of the western basin (Ivanoff, 1972).

Since 1965, we have regularly observed fish being marketed in the ports of the Golfe du Lion. The numbers of thermophilic species captured by fishermen over the past years is increasing. Several species, scarce until now, are more abundant, while others are new to the zone. *Diplodus cervinus cervinus* was unknown until 1980 and young and adult individuals are now fairly common. Quignard et al. (1962) reported *Epinephelus marginatus* twice in 1960 and 1962 and this species was not seen again until 1990. The presence of small individuals is now frequent, as is the case for the other French Mediterranean coasts. *Pomadasys incisus* was already present, but it has been caught more frequently since 1987. *Sphyraena sphyraena* is now more abundant in the Golfe du Lion, Port-Cros and Scandola. *Balistes carolinensis* has been very common since 1980, *Sardinella aurita* and *Pomatonus saltatrix* since 1991. *Solea senegalensis* was reported for the first time in 1986 (Quignard et al., 1986) and is now regularly captured. Most of these species are often present in the waters of the eastern Mediterranean rather than western basin (Whitehead et al., 1984–1986). Lastly, we have recently captured a circumtropical Tetraodontidae, *Sphoroides cutaneus*, in the Golfe du Lion. This species has already been caught in the south Mediterranean (Vacchi & Cau, 1985), but never in the north basin. Conversely, the septicentrional Clupeidae *Sprattus sprattus* which in the past was relatively abundant in the Golfe du Lion has become very scarce since 1988, although it is not captured by professional fishermen.

Stephens et al. (1988) have highlighted that changes in fish assemblages can reflect changes in oceanographic conditions and may be the first indication of an environmental shift. According to these authors, temperature is the most important large-scale variable which could affect fish populations. On the French Mediterranean coast, the northern records of southern species have always followed similar trends: (i) migration of small numbers of adult specimens are observed first and adult migration of fish species may be considered as a primary indicator of change (Stephens et al., 1988), resulting in an increased adult population of southern species; (ii) recruitment follows and juveniles can now be found.

The first hypothesis for explaining the modifications

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**TABLE 1**

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<td>Sc</td>
<td><em>Arbacia lixula</em></td>
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<td>26</td>
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<td>PC</td>
<td><em>Centrostephanus longispinus</em></td>
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<td>5–8</td>
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<td>Sc</td>
<td><em>Thalassoma pavo</em></td>
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—Missing data.
that we have observed in flora and fauna is that the capture of a new species or sudden abundance of another are only the result of a change in sampling regime. However, the three zones selected for this analysis have been under continuous scientific observation for many years (since 1965 for Port-Cros and Golfe du Lion; since 1975 for Scandola). Furthermore, the species retained are conspicuous and do not require specialist identification work. We may, therefore, be sure that they were not simply overlooked in preceding investigations. Also, the changes in abundance we have recorded are all too great (actual appearance or variation by a factor of 10 or more) to conceal a possible bias in sampling. We can thus disregard this initial assumption.

Secondly, these changes could result from local phenomena due to competitive inter- or intra-specific relationships or to other causes such as recruitment or diseases (Fletcher, 1987; Menge, 1991). A similar hypothesis does not involve a clear trend in the modifications. We have never recorded a southern extension of a species in the north-western basin and all the modifications described here are oriented. They show simultaneous northerly extensions of the biogeographical range of species common in the southern or eastern Mediterranean. While the observation of a new species of fish could correspond only to a geographical extension of a vagrant and mobile species (see discussion in Wheeler, 1986), the new occurrence of benthic species (algae, Echinioidea, Asteroidea) or of neotobenthic species (Soleidae) cannot be explained by such simple migration. In view of the number and variety of species studied here, the geographical position and diversity of the selected areas, we do not think that this is a local phenomenon caused by biotic factors, and we can also disregard this hypothesis.

Thus, these changes could indicate a more long-term change, as proposed by Francis (1990) and Tonn (1990), but what could be the cause? It is difficult to accurately interpret long-term observations of coastal water temperature and, therefore, to highlight a direct correlation between changes in coastal populations and an increase in temperature. Can these modifications be explained by other characteristics of the marine environment (turbidity, currents, chemical factors) or of the stations studied (with or without legal protection)? Changes in global basin-wide currents (liguro-provençal current) have not been documented in the western Mediterranean over the past 30 years and chemical components of Mediterranean waters in all the sites studied have not undergone significant modifications (Joanny et al., 1990) which could explain our observations. No modification of mean water turbidity has been recorded at Port-Cros or Scandola, although an increase in water turbidity can locally be observed in the Golfe du Lion, related to flow variations in the Rhône river. The marine environment is protected in the Port-Cros National Park and in the Natural Reserve of Scandola. This protection is over 18 years old and any potential protection-induced changes in flora and fauna have already taken place (Francour, 1992). Furthermore, we have also observed similar modifications in non-protected zones (for example, Golfe du Lion, Marseille and Nice). Therefore, protection, water cleanliness, chemical composition or currents cannot easily account for the coastal population changes recorded in the north of the western Mediterranean basin, and an increase of the water temperature remains the most probable cause.

In the literature, long-term coastal observations are scarce, but their analysis has shown correlation between temperature and abundance variations of a species, as is the case for the marine phanerogam Zostera marina, between 1897 and 1969 (Rasmussen, 1977) and for fish found along the west coast of the USA. (Mearns, 1988). The characteristics of the species examined in this paper and the caution that we have exercised in data selection (continuous sampling effort, well-known temperature tolerance) make it possible to state, therefore, that thermophilic species have become newly established or more abundant in the north-western Mediterranean waters, during the last several years. Simultaneous and recent biological changes are documented in the northern Atlantic (Tardy et al., 1985; Power, 1990), in the North Sea (Cushing, 1990) and in the northern Pacific (Ivanov & Samuylov, 1987; Wing & Mercer, 1990) and similar modifications might have already existed in the past. Therefore, we are not certain that the modifications described here are related to a long-term shift in climate.

Ecological consequences of increased mean temperature in shallow waters can be spectacular (for example, coral reef bleaching; Glyn (1991); Salvat (1992) and are often difficult to evaluate for an ecosystem (Pittock & Nix, 1986; Schindler et al., 1990). In the three zones we selected, it is still difficult to describe consequences. For example, the increase of the herbivorous sea-urchin Arbacia lixula can considerably modify coastal phytobenthos. It is also true that changes in the specific composition of ichthyofauna in the Golfe du Lion can have considerable impact upon the local fishing industries. These modifications may still be minor, but they should be more thoroughly analysed in terms of their ecological (Tonn, 1990) and economic (Francis, 1990; Healey, 1990) implications.


