

Recent Changes in Biodiversity in the Ligurian Sea (NW Mediterranean): is there a Climatic Forcing?

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ABSTRACT

A few case studies from the Ligurian Sea provide examples of how climate change has influence on marine biodiversity. This influence may be either direct (bryozoan population dynamics, coral growth, sea-grass shoot density) or indirect, mediated by biotic interactions (bivalves in a sandy bottom community) or marine currents (fish and rocky bottom communities, entering of southern species). The difficulty of distinguishing between anthropogenic and climatic actions on the marine biota emphasises the need to study marine biodiversity in the context of the physical setting and the relevant space and time scales.

Introduction

It has often been assumed, in the past, that marine communities were naturally stable, and that most changes (seasonal cycles apart) were probably caused by man (Lewis 1996). Only in the last decades the natural variability of marine communities has been fully recognised, and its relation with climate fluctuations hypothesised (Bianchi 1997).

Angel (1991) suggested that monitoring biogeographic boundaries would give an unambiguous signal of climate change. Evidence in that sense has been collected in recent years in different regions of the globe (Barry et al. 1995; Southward et al. 1995; Parker and Dixon 1998; Bianchi et al. 1998a).

The Ligurian Sea, situated in the north-eastern corner of the western Mediterranean, is one of the coldest areas of the Mediterranean Sea. Accordingly, the biota of the Ligurian Sea are characterised by a strong diminution of the sub-tropical elements and by a more marked presence of species of cold temperate waters (Rossi 1969). However, warm-water organisms have recently increased their occurrence in the Ligurian Sea (Bianchi and Morri 1993, 1994), providing a clue for climate change (Francour et al. 1994; Astraldi et al. 1995).

The aim of the present paper is to explore existing data on change in the Ligurian Sea biota in the search for further evidence for a climatic influence. First, the Ligurian Sea climate will be characterised in short and a climatic descriptor identified. The time trend of the climatic descriptor will be then compared with biological changes for different marine communities, studied especially in recent years.

Ligurian Sea Climate

The Ligurian Sea is tightly connected with the Gulf of Lion, which is subject to periodic intrusions of the northerly winds from the Rhone valley. They generate very energetic weather conditions, which are particularly severe in winter. The major large-scale hydrodynamic feature (Astraldi et al. 1994) is a well-defined cyclonic circulation active year round, which contributes to keeping the mean surface temperature lower than that of the adjacent Tyrrhenian Sea.

The greater cooling of the Ligurian Sea induces water and temperature losses, which in turn draw a seasonal flux of warmer Tyrrhenian Sea waters to restore the hydrological budget (Astraldi and Gasparini 1992). Analysing jointly current regimes and invertebrate settlement off

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Capraia Island (Fig. 1), Aliani and Meloni (1996, 1999) demonstrated that this Tyrrhenian current is the carrier of the dispersal stages of warm-water species into the Ligurian Sea. Notwithstanding seasonal variability, the flux is always directed northward and constitutes a sort of one-way bottleneck.

The different climatology of the two basins can be deduced from a number of hydrographic data, among which temperature is of primary importance. Many temperature measurements of Ligurian Sea waters are available since 1909 (Bruschi and Sgorbini 1986). Unfortunately, due to a temporal inhomogeneity in data sampling, it is not possible to derive long-term trends.

However, Astraldi et al. (1995) demonstrated that Ligurian Sea surface water temperatures are correlated to air temperature taken at the Meteorological Observatory of Genoa. Genoa air temperature in the last century shows important year-to-year fluctuations and two major warm periods: the first centred around the '40s, the sec-

ond started in the mid '80s and continuing at present (Fig. 2). The temperature trend from the '50s onward mostly parallels the North Atlantic Oscillation, which is considered as the main determinant of the marine climate in the Northern Hemisphere (Mann and Lazier 1996). Vignudelli et al. (1999) showed the influence of the North Atlantic oscillation on the circulation of the western Mediterranean Sea.

The present increase in air temperature coincides with the observed warming in deep (Bethoux et al. 1990) and intermediate waters (Sparnocchia et al. 1994), and is also mirrored in the nearly stable presence of warm-water species in the Ligurian Sea. There is also evidence that at least some of them, such as the labrid fish *Thalassoma pavo*, reproduce in the Ligurian Sea, thus being independent from the larval supply by the Tyrrhenian Sea (Vacchi et al. 2000). In summary, it seems reasonable to use Genoa air temperature time series as a synthetic descriptor of Ligurian Sea climate.

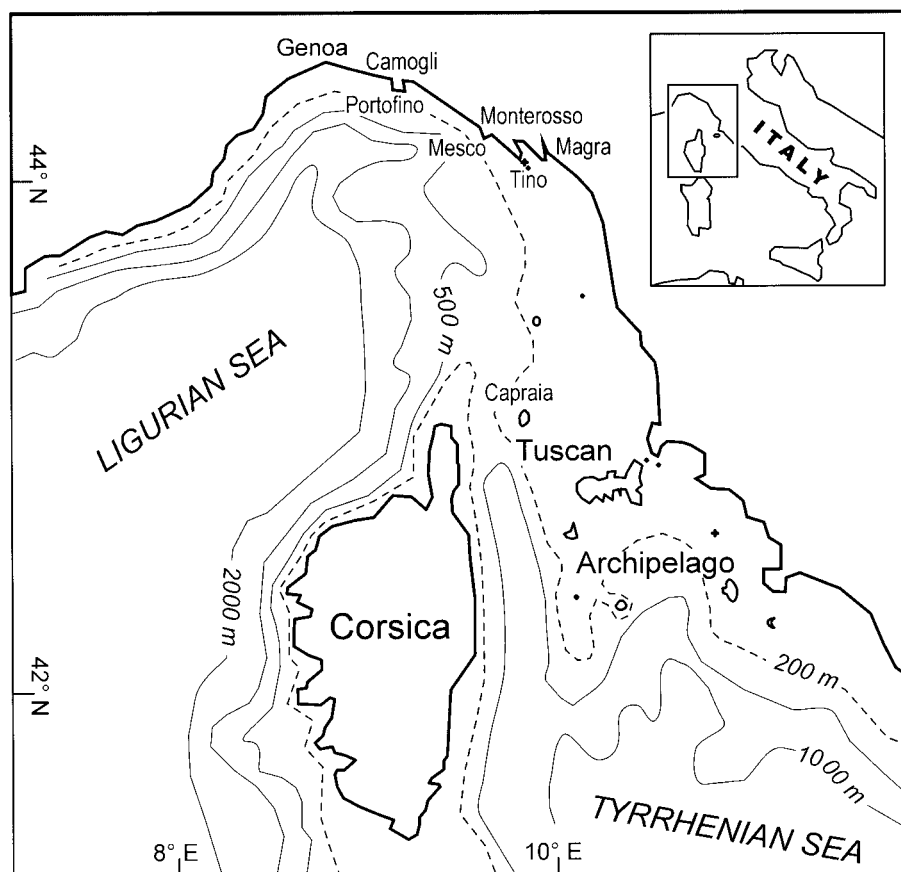
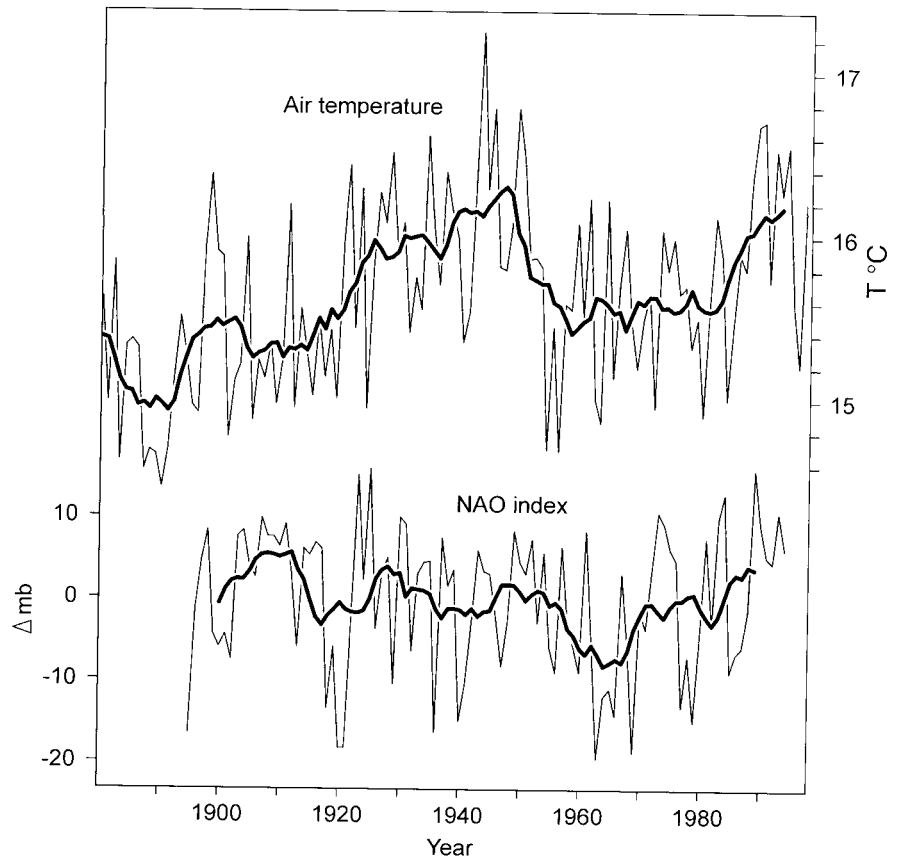


Fig. 1. Geographical setting of the Ligurian Sea, showing the boundary with the Tyrrhenian Sea (Tuscan Archipelago) and the localities mentioned in the text

Fig. 2. Trend of air temperature (annual means, T °C) at Genoa (Meteorological Observatory), 1880 to 1997; and trend of the North Atlantic oscillation index (average pressure differences between the Azores and Iceland, Δ mb), 1895 to 1994 (adapted from Mann and Lazier, 1996). In both graphs the *thick line* is the 11-year running mean



Change in Marine Communities

Sandy Bottom Benthos

Soft-bottom benthic communities of the Ligurian Sea have been studied for many years (Albertelli and Cattaneo 1985). Seasonal and interannual changes in a bivalve-dominated community inhabiting shallow sand were recently described by Albertelli et al (1993, 1994a, 1994b).

A short time series is available from the sandy bottom in front of the Magra River estuary (Fig. 1), where the benthic community was monitored for 7 years, 1987 to 1993 (De Biasi 1994, 1997). Major changes in community composition and structure were observed in 1988 and 1991: to relate the observed changes to the activity of a new sewage treatment plant (started in 1988, completed in 1990-1991) was tempting (Bianchi 1997), but a sharp decrease in mean air temperature, soon followed by a new rise, was observed in the same period (Fig. 2). Species richness, expressed as Margalef's $D = (S-1)/Lnn$ (where S

is the number of species and n the number of individuals), showed a trend nearly specular to that of air temperature. Dominance by the bivalve *Spisula subtruncata* coincided with the "warm" period 1988-1990, whereas another bivalve, *Chamelea gallina*, replaced *S. subtruncata* when temperature started rising again after 1991 (Fig. 3).

Rocky Bottom Benthos

Time series on epibenthic communities living on Ligurian Sea rocky reefs are scarce. A permanent station was fixed on a subtidal rock at Tino Island (Fig. 1), where a bryozoan-dominated community has been studied since 1993. The first results illustrate the importance of episodic climatic events, which are unpredictable in timing and extent, for the population dynamics of the dominant organism, the bryozoan *Pentapora fascialis* (Cocito et al. 1998).

Peirano et al. (1998) suggested using sclerochronology to compare the growth of the coral

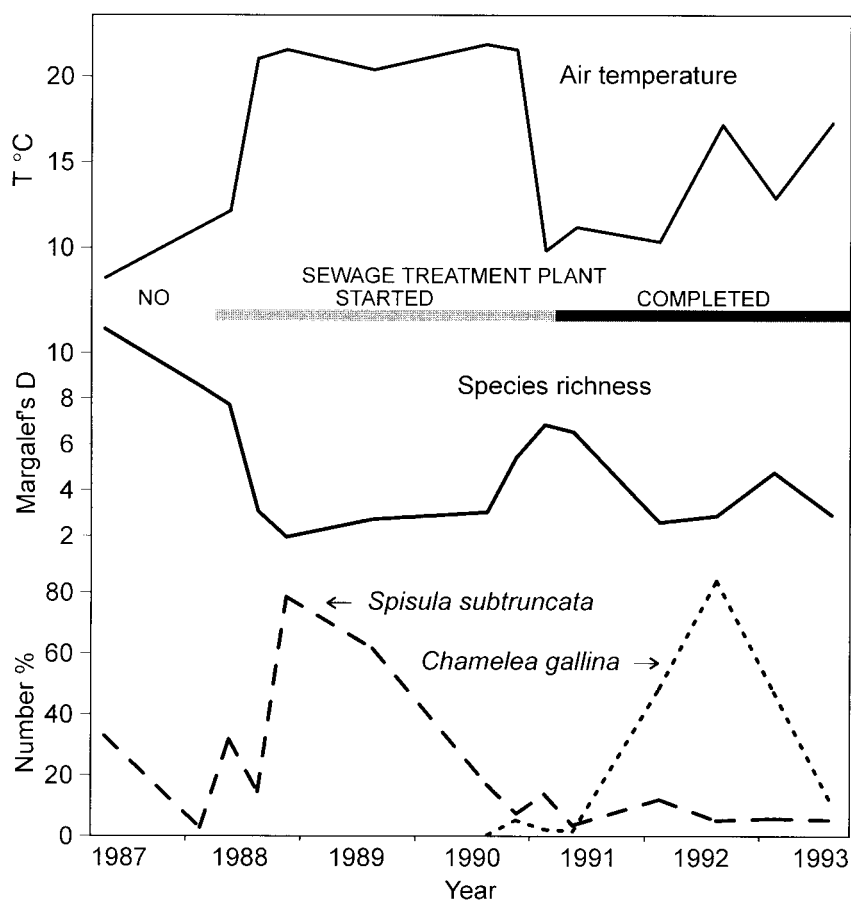


Fig. 3. Climate, anthropogenic, and biotic change in a soft bottom community, 1987 to 1993. Top to bottom: trend in air temperature at Genoa (each point represents the mean of the previous 3 months, $T^{\circ}\text{C}$); operation of a big sewage plant in the lower estuary of the Magra River; trend in species richness (Margalef's D) of the community inhabiting the sandy bottom in front of the Magra River estuary; quantitative importance (number %) of the two dominant species in the same community

Cladocora caespitosa with climate fluctuations. Timing of growth-band deposition in several colonies from eastern Ligurian Sea proved to be correlated to monthly temperature and irradiance (Peirano et al. 1999a). Retrospective analysis, through X-radiography, of the oldest colonies showed that higher growth rates coincided with a warmer period in the 40s, and lower ones with a colder period in the 70s, but showed little correlation with temperature in other periods (Morri et al. 2000).

Another way to approach the study of long-term change in rocky bottom communities is to "re-visit" sites already studied in the past. In the Ligurian Sea, two pioneering studies on rocky subtidal communities were done by Tortonese (1958, 1961) and Rossi (1965) thanks to the cooperation of amateur divers.

Tortonese (1958, 1961) worked at Portofino (Fig. 1) in the '50s and reported on the unexpected occurrence of several warm-water species. The previous decade coincided with a warm period (Fig. 2), but these species were also found

in other years in the Ligurian Sea (Bianchi and Morri 1994). We re-visited Tortonese's sites in 1991 and 1993 and concluded that no dramatic change had occurred in nearly half a century on these subtidal bottoms down to about 40 m depth (unpublished data). Nevertheless, we found as common a number of species, such as the algae *Pseudochlorodesmis furcellata* and *Zanardinia prototypus*, that Tortonese (1958, 1961) did not mention. Conversely, species reported as abundant in the '50s were unnoticeable in '90s. The most striking examples were the bivalve *Spondylus gaederopus* and the sponge *Calyx nicaeensis*. The virtual disappearance of the first might be due to a disease (Relini 1992) but we are unable to offer any explanations for the second: *C. nicaeensis* is a conspicuous species, easily to recognise underwater (see plate III B in Tortonese 1961), so it is difficult to think that it had escaped attention. Maybe it has been the object of excess collection as a curio, maybe its population collapsed for some other reason. However, the problem remains that Tortonese

(1958, 1961) used descriptions and samples taken by Duilio Marcante and the divers of the "Centro Subacqueo" of Genoa: the lack of precise, quantitative data prevents any conclusions.

A few years after Tortonese, in 1959 and 1962, Rossi (1965) worked at Punta Mesco (Fig. 1) with the help of the underwater photographer Gianni Roghi. Thanks to photography, she was able to provide (semi-)quantitative data of the sessile biota living on rocks 17 to 44 m deep. In 1990-1991, Peirano and Sassarini (1992) took photos in different stations of the same site, whereas in 1996 Peirano et al. (2000) were able to relocate both the 1959/1962 and 1990-1991 stations, taking new photographs of the epibenthic communities. Change was measured using the dissimilarity index 1-Sk, where Sk is the Kulczynski's similarity coefficient (Boudouresque 1971). Dissimilarity was significantly higher (1-way ANOVA, $P = 0.036$) between 1996 and 1959/1962

than between 1996 and 1990-1991 (Fig. 4). Peirano et al. (2000) related the bigger change from Rossi's time to increased water turbidity in the area. Based on the measurable raise of the compensation depth for seagrass (Torricelli and Peirano 1997), it can be calculated that water transparency (Secchi depth) passed from as much as 23 m to the present mean value of 11.4 m. Although human impact was presumed to be the main cause of this increased turbidity, the influence of climate fluctuations cannot be excluded, the '90s having been warmer than the late '50s (Fig. 4).

Sea-Grass Meadows

Posidonia oceanica is a seagrass species endemic to the Mediterranean Sea. Its meadows show at present alarming signs of degradation, especially

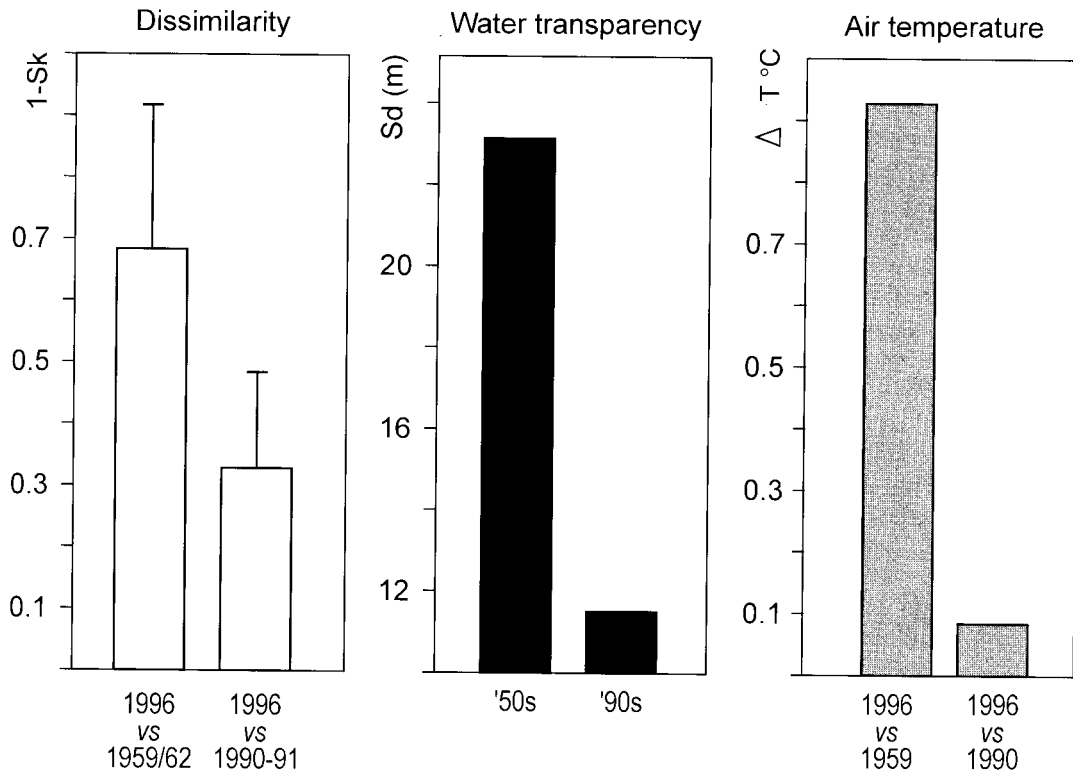


Fig. 4. Left to right: difference in subtidal rock epibenthic communities at Mesco Point, expressed as mean ($\pm$ standard deviation) dissimilarity (1-Sk) between 1996 and 1959/62 and between 1996 and 1990-91; water transparency in the same area in the '50s and in the '90s; difference in air temperature at Genoa (ΔT °C) between 1996 and 1959 and between 1996 and 1990 (in all cases the means of the 5 previous years were used)

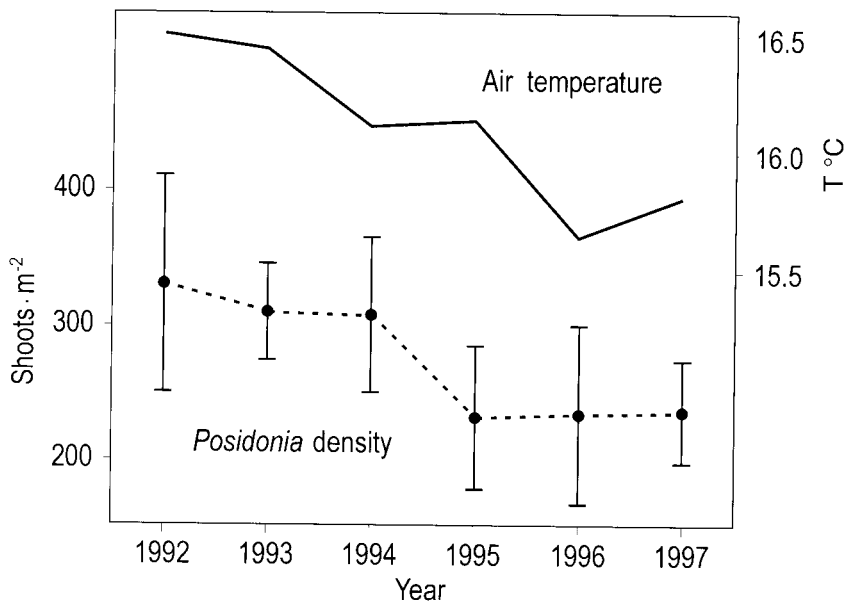


Fig. 5. Change in climate and in a *Posidonia oceanica* meadow, 1992 to 1997. *Top*: annual mean air temperature at Genoa ($T^{\circ}\text{C}$). *Bottom*: annual mean ($\pm$ standard deviation) of the density (shoots m^{-2}) at 10 m depth in the *Posidonia* meadow of Monterosso

in the northern parts of the Mediterranean. This degradation may be explained either by pollution, resulting in greater water turbidity and hence diminished plant vitality; or by the natural decline of the plant, which is believed to have had its climatic optimum around 6000-2750 years B.P. (Pérès 1984).

Regression of *Posidonia* meadows has been surely accelerating in recent decades: in the Ligurian Sea, for example, it can be reckoned that nearly 30% of their original surface area has been lost in the '60s, during the period of rapid urban and industrial development along the Ligurian coast (Bianchi and Peirano 1995; Peirano and Bianchi 1997). These years, however, also corresponded to a cold phase in the secular temperature trend (Fig. 2). In recent years, characterised by an apparent sea water warming (Bianchi 1997), flowering, fruit maturation and seedling occurrence have been more frequent (Piazzi et al. 1999).

A long-term study of the *Posidonia oceanica* meadow of Monterosso (Fig. 1) was started in 1991 and is still in progress. This meadow underwent heavy human aggression in the '60s and '70s (Góngora González et al. 1996), but is now included in a Marine Protected Area which should ensure its protection. A number of parameters has been monitored and their variation with time correlated with climatic data. Whether there is such a correlation or not is unclear at present (Bianchi 1997; Peirano et al. 1999b).

However, shoot density shows a pluriannual trend which parallels that of air temperature, thus suggesting an overriding influence of climate (Fig. 5).

Fish Communities

Fishery statistics often provide the longest time series of marine biological data available (Bianchi 1997). One of the best known series on Ligurian Sea fisheries was that of the so-called "tonnarella" of Camogli (Fig. 1). This tonnarella, described in detail by Cattaneo-Vietti (1985), was a fixed fishing net operating at the same location throughout spring and summer for many years. Balestra et al. (1976) reported catch data for the period 1950 to 1974. Although total catch was said to remain relatively constant over time (Boero 1996), its fluctuations grossly coincided with those of minimum air temperature. Species composition changed dramatically from a fish assemblage dominated by *Auxis rochei* in the '50s to one dominated by *Sarpa salpa* thereafter (Fig. 6). Balestra et al. (1976) explained the decreased abundance of the former as due to overfishing, and the increased abundance of the latter as a consequence of replacing nets made with hemp or nylon with nets made with coconut fibre, the latter being more easily fouled by algae which could attract the herbivorous fish *S. salpa*.

These *ad hoc* explanations may be convincing, but if we look at the trend of annual minimum air temperatures, we can see that most winters of *Auxis* years were less cold than those of *Sarpa* years. It might be not a coincidence that *A. rochei* is a warm-water species widely distributed in all tropical and subtropical seas of the globe, whereas *S. salpa* is a temperate water species, living in the Atlantic-Mediterranean region (Dubelius 1997).

Discussion

This short review of a few case studies shows that recent changes in Ligurian Sea biodiversity might well reveal a climatic forcing. According to Southward et al. (1995), climate change can influence marine communities by a combination of: (1) direct effect on the organisms (direct influence of temperature, causing changes in survival, reproductive success, dispersal pattern and

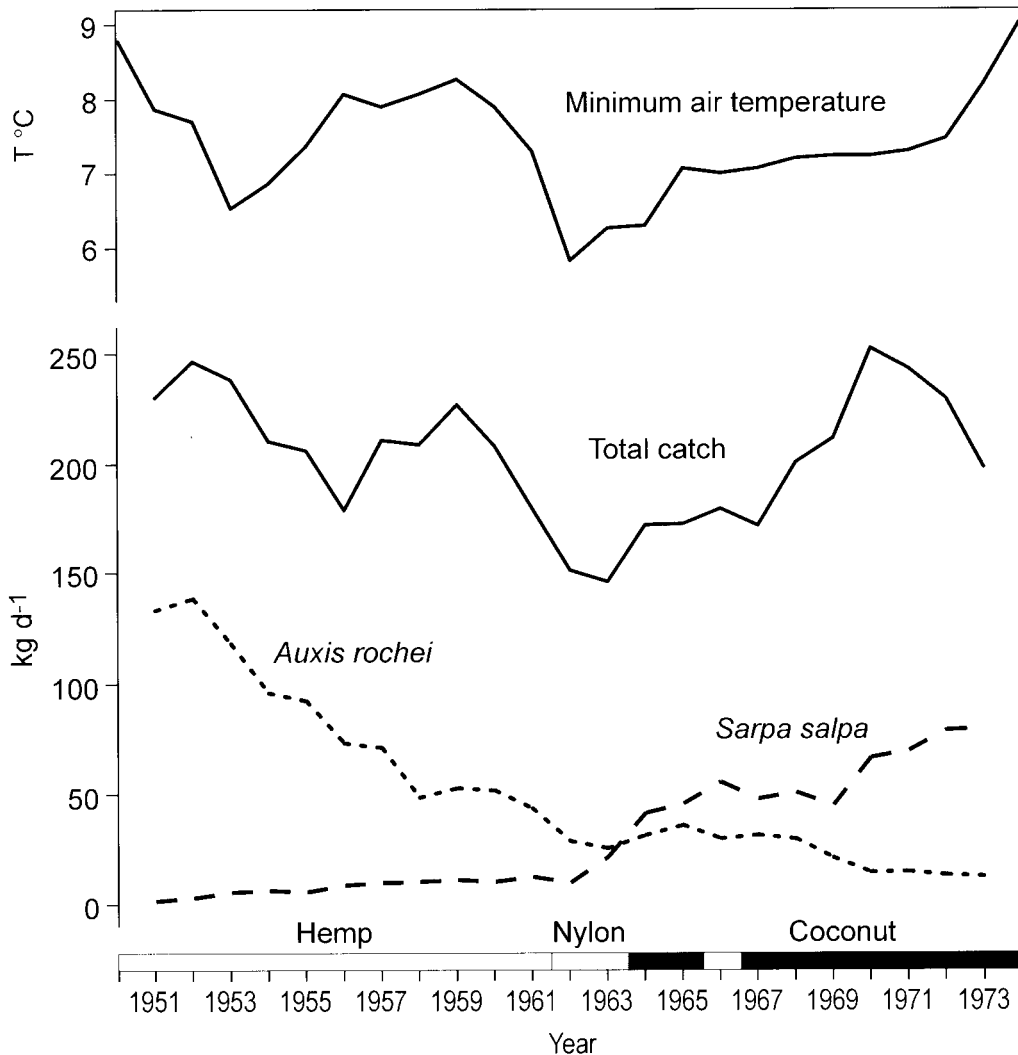


Fig. 6. Change in climate, fish catch and net fabric, 1950 to 1974. *Top to bottom:* trend in annual minimum air temperature at Genova ($T^{\circ}\text{C}$); trends in total catch and in the catches of the two most important fish species (kg d^{-1}) at the "tonnarella" (= fixed fishing net) of Camogli; fabric of the nets used in the tonnarella in different years: both hemp and nylon fibres inhibited covering by biofouling, coconut fibre did not

behaviour); (2) effects mediated by biotic interactions (conferral of competitive advantage to one of a pair of overlapping species); (3) indirectly through ocean currents (changes in climate may alter the emphasis of water flow and the pattern of water circulation). Note that this meaning of "direct" and "indirect" effects is different from that commonly used in community ecology (Strauss 1991). The data from the Ligurian Sea apparently provided examples for all these mechanisms.

Population dynamics of *Pentapora fascialis*, growth of *Cladocora caespitosa*, and change in shoot density of *Posidonia oceanica* seem to stand for a direct effect of climate on the organisms, whereas the alternate dominance between *Spisula subtruncata* and *Chamelea gallina* in sandy bottom communities might correspond with an effect mediated by conferral of advantage to one of them in turn. Both species are filter-feeding bivalves, sharing the same habitat, and a competition between them can be suspected.

The same hypothesis is not tenable in the case of the alternation between *Auxis rochei* and *Sarpa salpa*. The adults of two species occupy very different niches in the marine ecosystems and, although we probably do not know enough about the ecology of their larval phases, a competition is unlikely. Rather, we can think of the influence of an altered pattern of water flow. Changes in subtidal rock communities might also be due to such collateral effects, whereas the influence of current variability upon the occurrence of southern species in the Ligurian Sea seems sufficiently proved (Astraldi et al. 1995; Aliani and Meloni 1999).

Supply side ecology (Roughgarden et al. 1987) emphasises the role of physical transport processes in structuring marine communities, and Barry and Dayton (1991) coined the expression "hydrodynamic biological oceanography" to underline that the variations in the distribution and abundance of marine organisms are strictly linked to the movement of water masses. Veron (1995) introduced the concepts of "surface circulation vicariance" to indicate that the fluctuations in surface currents have a major impact on shallow marine life.

The alternation observed within bivalves and fish is consistent with the idea that climatic fluctuations favour the coexistence of species potentially redundant (Blandin 1987), thus act-

ing as a biodiversity pump on both evolutionary and ecological scales (Sarà 1985; Astraldi et al. 1995).

An aspect that turned out to be obvious in our analysis of these Ligurian Sea examples is that for most of them the observed change can be equally driven either by climate or by anthropogenic causes. Distinguishing between the two is often difficult (Bianchi 1997) and can also cause animated debates, as in the case of the alleged eutrophication of Skagerrak (Buhl-Mortensen 1996; Gray 1996). It is true that anthropogenic and climatic actions can combine their effects on the marine biota (Bourcier 1996). All this encourages caution when examining changes in marine ecosystems and emphasises the need of planning studies in the context of the physical setting and the relevant space and time scales (Levin 1992).

Finding an appropriate space and time scale was the main problem we met when designing the layout of this paper. After consulting both published data and our own archives, we clearly realised that most of the wealth of scientific research on the Ligurian Sea (Bianchi et al. 1987; Cattaneo-Vietti et al. 1988) concerns studies of local relevance and/or carried out for short periods. In part, this reflects the common Mediterranean research attitude, traditionally directed toward the identification and description of biocoenosis-types rather than the dynamic aspects (Bianchi 1997; Bianchi et al. 1998b). We are now getting fully aware that, contrary to the demand of most funding agencies, any small-scale and short-term approach to ecological monitoring and research will not enable us to understand ecosystem change, both climate or man-induced, but will likely result an unproductive investment of time and resources.

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