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# Global sea warming and “tropicalization” of the Mediterranean Sea: biogeographic and ecological aspects.

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## SUMMARY

The so-called “tropicalization” of the Mediterranean is the result of four different phenomena: Atlantic influence, lessepsian migration, species introduction by humans, and sea-water warming; all these factors concur favouring the occurrence and spreading of thermophilic species through the Mediterranean Sea.

## INTRODUCTION

There is now substantial evidences that the climate of our planet is in a phase of change and that, for instance, the average surface temperature of the sea is increasing (Bianchi, 1997). While the long-term effects of this warming are still debated, the responses of the marine biota are already visible: the increased temperature caused, for instance, the recent bleaching and consequent massive mortality of corals in all the oceans (Wilkinson, 2000). This and other similar events in the tropics attracted the attention not only of scientists, but also of public opinion, mass media, and managers, because of the strong impact on the tourism, fishery and other economic activities linked to coral reefs. The Mediterranean Sea, the widest marine warm-temperate region in the world, has a role of climatic and biogeographic hinge between tropical and temperate seas (Bianchi and Morri, 1999). Which consequences will the warming trend have on the Mediterranean Sea? It is often said that the Mediterranean is going towards a generalised phenomenon of “tropicalization”, i.e., the increased occurrence of warm-water biota. The tropicalization of the Mediterranean

cannot be considered just as a sort of improbable return of this sea to its ancient past of equatorial Mesozoic ocean, the Tethys. It may rather be seen as the resultant of changes, not necessarily correlating among each other, induced by climate and human action. This paper aims to analyse the main patterns of the Mediterranean Sea tropicalization; its extent and consequences are also shortly considered.

#### ATLANTIC AND RED SEA INFLUENCES

Today, the Mediterranean Sea is in an interglacial phase: as happened already during the Quaternary, the Atlantic water, entering through Gibraltar, carries into the Mediterranean species of sub-tropical affinity prevalently. Many of these species establish exclusively in areas close to Gibraltar, such as the Alboran Sea and the coasts of northern Africa and southern Spain, but some penetrate farther east, reaching, for instance, the coasts of Sicily.

On the other side of the basin, the penetration of Red Sea species through the Suez Canal has increased in the last decades, because of the reduction of salinity of Bitter Lakes, that at first were an almost insuperable obstacle to the passage of organisms. The building of the Aswan dam reduced the Niles outflow, therefore facilitating the spreading of stenohaline Red Sea species to the west. The species entering in the Mediterranean through the Suez Canal are called “lessepsian” from the name of the engineer Ferdinand de Lesseps, the French diplomat who promoted the cutting of the Canal. Lessepsian migration represents the major biogeographic change presently occurring in the world ocean (Bianchi et al., 2002).

#### THE FOOTPRINT OF HUMANS

Beside lessepsian migration, humans voluntarily or involuntarily cause, by the marine traffic, the passive introduction in the Mediterranean Sea of many exotic species, coming from other seas of the world. Rather curiously, species introduced by humans are nearly always typical of warm waters.

As far as we know, most of the anthropogenic introductions in the Mediterranean Sea took place in the very last decades. However, we do not know to what extent the accidental introduction of exotic species by humans might have taken place in the historical past. Early before Christian era, Greeks travelled perhaps to Iceland, Phoenicians circumnavigated Africa, and Punics possibly reached Macaronesia, Brazil and the Maldives. After the discovery of America, thousands of Spanish galleons started to cross the Atlantic regularly. Ships of ancient times had wooden hulls, with no antifouling paints. They anchored in bays with a rich and diverse marine life, not in polluted harbours like today. How

many species were they carrying with them? How many exotic species were accidentally introduced in the Mediterranean at that time and got subsequently naturalised? We are well aware of this phenomenon on land: much of the so-called typical Mediterranean vegetation is of exotic origin, in reality. But we tend to underestimate the potentiality of the same phenomenon in the sea. The list of exotic animals and plants that invaded the Mediterranean is getting longer every day (Occhipinti, 2002). Species are intentionally or accidentally introduced into the Mediterranean via ship fouling, ballast waters, aquaculture, trade of living bait, wrapping of fresh seafood with living algae, aquariology, and even scientific research! As on land, acclimated exotic species might supplant indigenous species and, by altering trophic webs and interspecific relationships, induce profound modifications in the original ecosystems (Bianchi and Morri, 2000).

## CLIMATE CHANGE

According to Southward et al. (1995), climate change can influence marine communities by a combination of both direct and indirect effects. Direct effects depend on the fact that temperature affects organisms, influencing their survival rate, reproductive success, dispersal pattern and behaviour. Indirect effects may be mediated by biotic interactions or may operate through marine currents. In the first case, there may be conferral of competitive advantage to one of a pair of overlapping species, increased incidence of a parasite, or modified abundance of preys and/or predators. In the second case, climatic change may alter the emphasis of water flow and the pattern of water circulation, with great repercussions on dispersal ability of marine organisms. All these mechanisms have been shown to be acting on the NW Mediterranean biota (Morri and Bianchi, 2001; Chevaldonné and Lejeune, 2003). Perhaps, the change operating through marine currents has provided the most spectacular examples (Astraldi et al., 1995).

## MARINE CURRENTS AND SPECIES DISTRIBUTION

The water-mass circulation within the Mediterranean is triggered by a stable surface current due to the entrance of Atlantic water through the Strait of Gibraltar. Once in the Mediterranean, this water of Atlantic origin circulates anti-clockwise, reaching every sub-basin of the Mediterranean. Obviously, the Atlantic current modifies gradually as it penetrates in the inner parts of the Mediterranean. The characteristics of the Atlantic water appear little altered in the most of the western basin (between Gibraltar and the Italian peninsula) but in some particular areas as the Tyrrhenian Sea and the Liguro-Provençal basin, where they undergo greater warming and cooling, respectively. The Strait of Sicily divides the western basin of the Mediterranean from the eastern one (from

the Italian peninsula to Israel coasts). In the eastern basin, the Atlantic water keeps flowing anti-clockwise, but modifies much greatly: it become generally warmer and saltier, except than in the Adriatic and the northern Aegean seas. It could therefore be supposed that the marine biota of the western and eastern basins are very different from each other. This is true only in part: if recent introductions (the already mentioned Atlantic migrants or the lessepsian species) are excluded, there are no many examples of species occurring exclusively in only one of the two basins (Bianchi et al., 2002). For instance, the genus *Charonia*, one of the biggest Mediterranean gastropods, is represented in the western basin by *C. lampas*, with a broader shell and a red coloured body; in the eastern basin by *C. tritonis*, with a slender shell and a yellow coloured body: the two species meet in the Strait of Sicily. This strait could therefore represent a barrier to the spread of the species from one Mediterranean basin to the other. Recent research by Greek, Italian and French scientists, however, cast doubt on the fact that the Strait of Sicily is really an efficient filter to the eastward spreading of the fauna of the Western Mediterranean (Morri et al., 1999; Logan et al., 2002).

A common example of a western species that was said “not to go to the east” is a beautiful colonial scleractinian, with a livery orange colour: *Astroides calycularis*. Distributed from Guinea to the Southern Italian coasts, it reaches Ventotene to the north and the Strait of Sicily (exactly!) to the east. It was explained that *A. calycularis* cannot go east because the life-span of its pelagic larva is too short to overtake the wide expanse of the Ionian Sea by means of the Atlantic current. On the other hand, it could not cross this sea step by step along the coast: the northern coast would be too cold for this thermophilic species, the southern coasts are sandy and do not offer this rocky bottom species place to settle (Pérès and Picard, 1964). All these explanations, however, did not convince *Astroides calycularis*, which has been recently discovered along the coasts of Croatia, in the Adriatic Sea (Kružić et al. 2002)!

#### A SCOPE FOR BIOGEOGRAPHY

Monitoring marine areas near biogeographic boundaries may provide unambiguous clues on the role of climate changes. Examples in that sense are already know from various parts of the world (Bianchi et al., 1998a). The Ligurian Sea is one of the coldest biogeographic sectors of the Mediterranean Sea. As a consequence, the Ligurian Sea biocoenoses are characterised by a strong reduction of subtropical species and a more relevant presence of temperate species. Nevertheless, a greater occurrence of subtropical species, correlated to the present phase of climate warming, has been recently observed in the Ligurian Sea waters (Bianchi and Morri, 1993, 1994). Some of these subtropical species, such as the wrasse *Thalassoma pavo*, are

now able to reproduce also in the Ligurian Sea, thus getting independent from the larval supply and establishing “naturalized” populations also in this basin (Vacchi et al., 1999, 2001; Sara and Ugolini, 2001; Guidetti et al., 2002). In many cases, unfortunately, the need of knowing if the range of a particular thermophilic species is expanding must face the lack of sufficient knowledge about the former distribution of the species. While the case of *Thalassoma pavo* is indisputable because the species is conspicuous and easy to recognise, the same cannot be said for *Arbaciella elegans*, a small sea-urchin with subtropical affinity which hides in anfractuositities or under stones and which has been long known in the warmest sectors of the Mediterranean Sea. In the last years it has been recorded frequently even in the colder Ligurian and Adriatic seas (Grubelić and Antolić, 2000): are those new occurrences or nobody noticed the species there before?

#### ARE MEDITERRANEAN ECOSYSTEMS CHANGING?

Tropical marine ecosystems are characterised by coral reefs. True reefs do not exist in the Mediterranean, but several Mediterranean organisms are capable to build significant bioconstructions. These organisms include primarily coralline algae, but also some animals, such as scleractinian anthozoans, vermetid molluscs, serpulid polychaetes and cheilostomate bryozoans.

The bioconstructions of the Mediterranean are monospecific or, at most, oligospecific, as far as the species responsible for their building are concerned. From this point of view, the Mediterranean Sea conforms to the empirical rule that the diversity of bioconstructors decreases when latitude increasing. The winter surface isotherm of 14°C, that cuts in two the Mediterranean Sea along a line joining, from west to east, Valencia-Cagliari-Naples-Bari-Athens-Rhodes, seems to represent the northern limit for the bioconstructional activity of the vermetid *Dendropoma petraeum* and, perhaps, of the scleractinian *Madracis pharensis*. Similarly, it seems that the bioconstructional activity of coralline algae has been more intense during the periods of the past having a warmer climate. Taken as a whole, these facts suggest that the present-day Mediterranean is a sort of hinge zone between a marine biota dominated by bioconstructors and one deprived of them. The carbonate production by Mediterranean bioconstructors, taking into account both corals and other organisms, may be estimated around  $10^3 \text{gCaCO}_3 \text{m}^{-2} \text{y}^{-1}$ , so being included in the range recorded for the tropics (Bianchi, 2002).

Eight coral species, out of the 37 presently occurring in the Mediterranean, are potential bioconstructors (Morri et al., 2000a). Five of them are always deprived of zooxanthellae as they live in deep waters, which are not reached by the light necessary to their microalgal endosymbionts. *Dendrophyllia ramea* and *Dendrophyllia cornigera* are known as “yellow corals” and live toward the deep

boundary of circalittoral zone, especially in the south-western areas of the Mediterranean, therefore showing a distribution typical of thermophilic species. *Madrepora oculata*, *Desmophyllum cristagalli* and *Lophelia pertusa* are grouped under the name of “white corals”, live in the bathyal zone and have a strong affinity for cold waters. The three littoral species, obligatorily or facultatively zooxanthellate, are *Madracis pharensis*, *Oculina patagonica* and *Cladocora caespitosa*. *Madracis pharensis* occurs, without zooxanthellae, in submerged caves all over the Mediterranean, without showing no significant bioconstruction capacity; in the south-eastern Mediterranean, however, it may be found outside caves and with zooxanthellae, and in these situations it may play a significant bioconstructional role. *Oculina patagonica*, probably originating from south-western Atlantic, has been involuntarily introduced by humans in the Mediterranean: it is normally zooxanthellate, but can survive for long time also without zooxanthellae, and is able to build big colonies. *Cladocora caespitosa*, the only species studied with some details, is obligatorily zooxanthellate and may build banks more than one meter thick and several tens of meters wide (Morri et al., 1994, 2000b, 2001; Peirano et al., 1998, 2002; Rodolfo-Metalpa et al., 2002a,b). This species belongs to the family Faviidae, one of the most important in coral reefs, and its calcification rates compare with those of tropical hermatypic corals (Rodolfo-Metalpa et al., 1999; Peirano et al., 2001). Growth of *Cladocora caespitosa* seems to be correlated with climate fluctuations. Retrospective analysis, by X-radiography, on colonies older than 60 years, demonstrated that the highest growth rates coincided with the “warm” period of the 40’s and the lowest with the “cold” period of the 70’s (Peirano et al., 1999). This agrees with the palaeoecological information, indicating that *C. caespitosa* was more abundant – and its formations more conspicuous – during the warm periods of the Quaternary, and especially during the Tyrrhenian stage, with high subtropical affinity (Peirano et al., 2004). It can therefore be supposed that, if the present sea water warming continues, *Cladocora caespitosa* will play the role of constructional coral in a more and more “tropical” Mediterranean Sea. In reality, in coincidence with positive anomalies of sea surface temperature recorded in these last summers, this species underwent mass-mortality, recalling those observed in the tropics (Rodolfo-Metalpa et al., 2000)! Cases of mass-mortality apparently correlated with high temperatures were recorded also in other organisms, such as sponges and gorgonians (Cerrano et al., 2000).

#### CONCLUDING REMARKS

There is no doubt that the biota of the Mediterranean is changing (Bianchi et al., 1998b). Atlantic influx, lessepsian migration, human action and present climate warming jointly favour the occurrence and the spread of thermophilic

species, being these indigenous of the Mediterranean Sea or having been introduced directly or indirectly by humans. The so-called “tropicalization” of the Mediterranean has to be considered as due to the combination of these four factors and has little to do with the ancient geological history of the basin.

The Mediterranean marine biota changed dramatically during the geological past, and is still continuously changing under the influence of both humans and climate. Climate change is sometimes viewed as one of the most important threats to marine biodiversity. On the other hand, climatic fluctuations may act positively on biodiversity, favouring the coexistence of species potentially redundant from a functional standpoint and thus allowing the formation of species-enriched assemblages. Recent climatic cycles have acted as a diversity pump on both evolutionary and ecological scales (Astraldi et al., 1995).

It is impossible at present to foresee to what extent the exuberance of thermophilic species in the Mediterranean Sea of tomorrow will affect the trophic web and, more in general, the functioning of marine ecosystems. On the other hand, Mediterranean Sea ecosystems do not seem to date to be acquiring a more marked tropical physiognomy, at least as far as constructional organisms and especially corals are concerned: the coastal ecosystems of the Mediterranean Sea still keep being dominated by frondose algae, even if the species that are getting supremacy belong to tropical genera, such as *Caulerpa* or *Styopodium!*

A better knowledge of what is going on in the Mediterranean Sea requires continued research work in those scientific areas currently unfashionable with funding agencies: systematics, biogeography and taxonomy. Specialists in these disciplines getting retired are not replaced by young students: thus, while biodiversity problems are growing, we are losing expertise in biodiversity (Boero, 2001).

To understand the effect of the tropicalization of the Mediterranean Sea, it is essential to start monitoring biodiversity at a broad geographic scale. Neither species nor ecosystems recognise the borders of nations, nor climate and even human impacts do so. An internationally co-ordinated network would be essential to long-term projects of research. Such projects need to encompass at least the expected lifetime of the dominant organisms and the time scale of the most important factors that influence them (Bianchi and Morri, 2000). With a small-scale and short-term approach to ecological monitoring and research, attempts to predict ecosystem change, both natural or human-induced, will risk to fall into frustration.

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I lavori saranno accettati se scritti in italiano o in un buon inglese. I dattiloscritti dovranno essere privi di correzioni a penna o ritocchi, battuti con macchine elettriche e preferibilmente supportati dal dischetto IBM compatibile.

Ogni lavoro dovrà incominciare con il titolo, seguito dai nomi e cognomi degli autori in extenso, seguiti dall'Istituto di appartenenza, Key words (5) e da un summary (senza titolo) in lingua inglese, mentre non si pubblicano riassunti in italiano. Nel lavoro potranno essere distinti una introduzione, un capitolo di osservazioni, uno di conclusioni. Le figure (di una grandezza massima di cm 11,5 x 18), siano esse fotografie montate in tavole (su cartone bianco), fotografie isolate (pure incollate su cartone bianco), disegni a tratto o grafici, dovranno essere numerate progressivamente in numeri arabi a partire da 1. I numeri, in caratteri trasferibili, dovranno essere applicati direttamente in basso a sinistra su ciascuna immagine montata in tavole. Le spiegazioni (Fig. 1, Fig. 2 ecc.) dovranno essere nella stessa lingua del testo e battute su fogli a parte. Nel testo le figure saranno richiamate come (Fig. 1; Figg. 1 e 2 o Figs. 1 and 2). Le tavole non hanno numerazione propria, ma solo quella progressiva delle figure che le compongono. Le tabelle dovranno avere un titolo, saranno numerate in progressione con numeri romani (Tab. I, Tab. II) e così saranno richiamate nel testo.

I nomi delle specie e dei generi verranno stampati in corsivo e dovranno essere sottolineati una volta nel dattiloscritto a cura dell'Autore. I raggruppamenti sistematici di rango maggiore saranno stampati in tondo. Si consiglia che le stazioni di cattura italiane siano identificate con riferimento al sistema U.T.M.

I lavori citati nel testo saranno indicati con Autori e data, scritti in tondo come il resto del testo, come segue: Vaillant (1976), Taiti e Manicastro (1980), Baroni Urbani et al. (1978); (Vaillant, 1976); (Taiti e Manicastro, 1980); (Baroni Urbani et al., 1978).

Ciascun lavoro dovrà essere concluso con una Bibliografia, in ordine alfabetico, accuratamente dattiloscritta e redatta secondo lo schema seguente:

Per i lavori in lingua italiana i numeri decimali devono essere indicati con la virgola (es. 0,6; 2,5), mentre nei lavori in lingua inglese si dovrà utilizzare il punto (es. 0.6; 2.5).

BARONI URBANI C., RUFFO S., VIGNA TAGLIANTI A.. 1978 - Materiali per una biogeografia italiana fondata su alcuni generi di Coleotteri Cicindelidi, Carabidi e Crisomelidi. Mem. Soc. entomol. ital., 56 (1977): 35-92.

SBORDONI V., FORESTIERO S. 1984 - Il mondo delle farfalle. Mondadori, Milano, 312 pp.

TAITI S., MANICASTRI C. 1980 - *Cylisticus aprutianus*, nuova specie di Isopode terrestre dell'Abruzzo (Crustacea, Oniscoidea). Fragm. entom., 5: 253-258.

VAILLANT F. 1976 - Some Philopotamidae from France. In: H. Malicki (ed.), Proc. First Int. Symp. on Trichoptera, Junk, The Hague: 25-31.

I testi dattiloscritti, in duplice copia, e le figure (gli originali per la pubblicazione e una fotocopia) dovranno essere confezionati fra cartoni e fatti pervenire al prof. Baccio Baccetti, Istituto di Biologia Generale, Via T. Pendola 62, 53100 Siena.