The advance of thermophilic fishes in the Mediterranean Sea: overview and methodological questions

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Abstract

This paper focuses on the advance of thermophilic fishes in the Mediterranean Sea, a phenomenon that has received increasing attention in recent times. By reviewing published records of the last 15 years, a list of 51 species occurring northwards with respect to their known distribution ranges, is compiled. With only two exceptions, all of them have a sub-tropical and tropical character and many of them can be considered as good indicators of climate warming. Methodological possibilities, suitable to perceive this complex process of change, are raised and discussed.

Introduction

Climate is one of the most important determinants for living organisms, shaping the distribution of plants and animals all over the planet trough the combination of direct and indirect effects. In poikilothermic organisms such as fishes[1], the temperature may shape population and community structures, through its direct influence on the survival, reproduction and patterns of resource use of single individuals. Effects of temperature on marine organisms can be also mediated by indirect effects such as by the modification in water circulation, with clear consequences on larval dispersal and recruitment (Bianchi and Morri, 2004). Fishes have long been used as indicators of environmental changes (Mearns, 1988; Stephens *et al.*, 1988; Roessig *et al.*, 2004). Their high dispersal potential, ecological differentiation, general non-resilience, sensitivity to temperature, large size and ease of identification, make them excellent candidates for the study of the effects of climate variability (Wood *et al.*, 1997). In addition, the Mediterranean Sea, located in the temperate zone of the northern hemisphere, includes species with different origin and thermal tolerance, providing an excellent field of investigation.

The advance of thermophilic fishes

Up to now, not many ecological efforts have been directed to understand the role that climate warming plays in controlling Mediterranean fish dynamics but biotic consequences have already emerged. Climate warming is driving species ranges toward the poles (Walther *et al.*, 2002; Parmesan and Yohe, 2003; Root *et al.*, 2003; Perry *et al.*, 2005) and this ‘harbinger’ is now perceptible in the Mediterranean realm, where a variety of thermophilic organisms belonging to macroalgae, plankton, invertebrates (Bianchi, 2007) and - as we will see - fishes, are extending their distribution towards northern areas.

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[1] Exceptions of partial endothermy are known for some sharks, tunas and billfish.

Thermophilic fishes have evolved in tropical or subtropical marine environments and hence are adapted to warm waters. In the Mediterranean, these species can be broadly categorized into two major groups, which are distinguished by different histories:
1) NATIVE fishes, with tropical or subtropical affinity and origin, entered in the Mediterranean during previous interglacial phases of the Quaternary. These species occur typically in the southern Mediterranean, where water temperature is higher than average. The northern spread of the native warm water biota has been named “meridionalization” by some (Bianchi and Morri, 1993; 1994; Riera *et al.*, 1995).
2) EXOTIC fishes, have recently entered the Mediterranean, mainly from the Red Sea or from the Atlantic Ocean. These species have taken advantage of suitable pathways for dispersal, i.e. the Strait of Gibraltar and the Suez canal, and are found mainly in proximity of their entry point, in the western and eastern sectors of the Mediterranean, respectively. This phenomenon enhances the tropical character of the Mediterranean and can be indicated as “tropicalization”[2] (Andaloro and Rinaldi, 1998; Bianchi and Morri, 2004; Bianchi, 2007). Another definition that has been used is “demediterraneization” (Quignard and Tomassini, 2000), to put the emphasis on the process of biotic homogenization of the Mediterranean Sea.

In the last two decades, the advance of thermophilic species has represented the first and most cited evidence of the linkage between climate change and distribution patterns of Mediterranean Sea biodiversity. When consequences of climate warming still had a hypothetical character, these ‘unusual occurrences’ have served as sentinels, by providing the first indication of changes that (maybe) were still not clearly evident in the temperature records (Riera *et al.*, 1995; Francour *et al.*, 1994). By reviewing the relevant literature of the last 15 years (Table 1 – see page 44), a total of 51 Mediterranean fishes, were founded to have expanded northwards. Among them, I counted 34 native and 17 exotic species (6 Atlantic and 11 Lessepsian[3]) (Figure 1a). Most of these species have a subtropical or tropical character and live mainly in coastal habitats, whilst only two species live in deep waters (Figure 1b). Serranidae (N=6 species) and Carangidae (N=5 species) were the most represented families, showing a good coherence in their response.

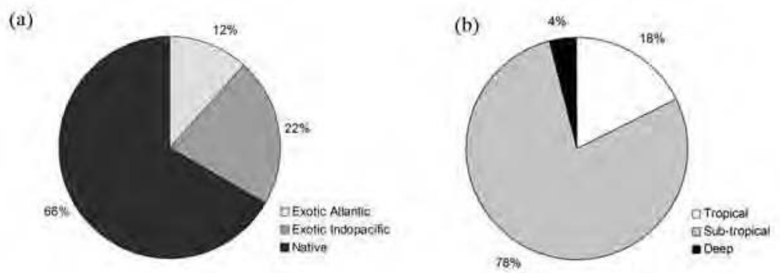

Fig. 1. Percent distribution of Mediterranean northward expanding fish species, based on the relevant literature records of the last 15 years: (a) distribution according to their geographic origin (Native, Atlantic, Indo-Pacific); (b) distribution according to their climate affinity (tropical, sub-tropical, deep). N = 51.

The bulk of these ‘northwards records’ came from the Adriatic Sea (Dulčić *et al.*, 1999; Dulčić and Grbec, 2000; Dulčić *et al.*, 2004 and references therein included), where even juveniles of various thermophilic fishes, e.g. *Trachinotus ovatus* (Dulčić *et al.*, 1997a), *Sparisoma cretense* (Guidetti and Boero, 2001) *Pomatomus saltator*, *Stromateus fiatola* (Dulčić *et al.*, 2000) and *Campogramma glaycos* (Dulčić *et al.*, 2003), have been recently registered. Furthermore, new species are now appearing in the coldest sectors of the Mediterranean, such as the northern Adriatic Sea (Parenti and Bressi, 2001; Bettoso and Dulčić, 1999; Sinovčić *et al.*, 2004; Psomadakis *et al.*, 2006) the northern Aegean Sea (Karachle *et al.*, 2004; Psomadakis *et al.*, 2006; Tsikliras and Antonopoulou, 2006) and the Gulf of Lion (Francour *et al.*, 1994). These areas are considered as the hotspots for

[2] In a different way, the term ‘tropicalization’ has been referred to fish stocks, to indicate smaller body sizes and age/length at maturity as consequences of fishing (see Stergiou, 2002 and references therein included). Lloris (2007) has used this term to indicate the poleward displacement of tropical species (not just the exotic ones).

[3] Species coming from the Red Sea that have entered the Mediterranean through the Suez Canal (Por, 1978).

endemic species and concern has been expressed for their conservation in view to the advance of thermophilic species (Ben Rais Lasram and Mouillot, 2008).

Meridionalization

Looking at native fishes, we are probably used to have just few examples of 'meridionalization' (e.g. the Mediterranean parrotfish *Sparisoma cretense,* the ornate wrasse *Thalassoma pavo,* the dusky grouper *Epinephelus marginatus* and the barracuda *Sphyraena viridensis*). Instead, this phenomenon can be illustrated by a large series of new presence records (Table 1 – see page 44). Moreover, increasing abundances have been recently demonstrated for *Sardinella aurita* (Sabatés *et al.*, 2006) and possibly for other southerly species such as *Caranx crysos*, *Caranx ronchus* and *Balistes capriscus* (Bradai *et al.*, 2004).

Tropicalization

The other component of thermophilic ichthyofauna is represented by exotic fishes that demonstrate a clear increase in their invasion rate (Ben Rais Lasram and Mouillot, 2008). These species have now attained an extraordinary relevance for the Mediterranean biodiversity. Today, we can count 111 exotic fishes, nearly the 16% of Mediterranean ichthyofauna[4] and almost all of them are of tropical and subtropical origin (Golani *et al.*, 2002; Golani *et al.*, 2007). Evidences of geographical extension (Table 1 – see page 44) are particularly numerous for species coming from the Red Sea. The latest and most remarkable case is undoubtedly the bluespotted cornetfish, *Fistularia commersonii,* which has been observed for the first time in 2000 in Israel (Golani, 2000) and soon afterwards recorded all over the eastern and central Mediterranean coasts (Azzurro *et al.*, 2007b), up to the proximity of the Strait of Gibraltar (Sánchez-Tocino *et al.*, 2007). A few kilometers more and we will have the first case of 'trans-Mediterranean migration', from the Indo-Pacific to the Atlantic Ocean! Less pronounced may the expansion of Atlantic subtropical invaders appear, but their introduction rate has been clearly correlated with the temperature (Ben Rais Lasram and Mouillot, 2008) and significant longitudinal spreads have recently observed (Ragonese and Giusto, 2000; Corsini *et al.*, 2006; Ben Rais Lasram and Mouillot, 2008).

In our inventory of north expanding species (NES), several fishes have been included on the basis of one single record. I have also considered *Fistularia petimba,* even if its expansion has been documented only in extra-Mediterranean sightings. Within these limitations, the list attempts to define a groups of species which is responding to the same historical process. Here, the average taxonomic distinctness AvTD (Warwick and Clarke, 1995) has been used to compare NES with other group of Mediterranean fishes. This index is a measure of the taxonomic complexity which takes into account the taxonomic distances between species[5]. According to Figure 2, AvTD of NES

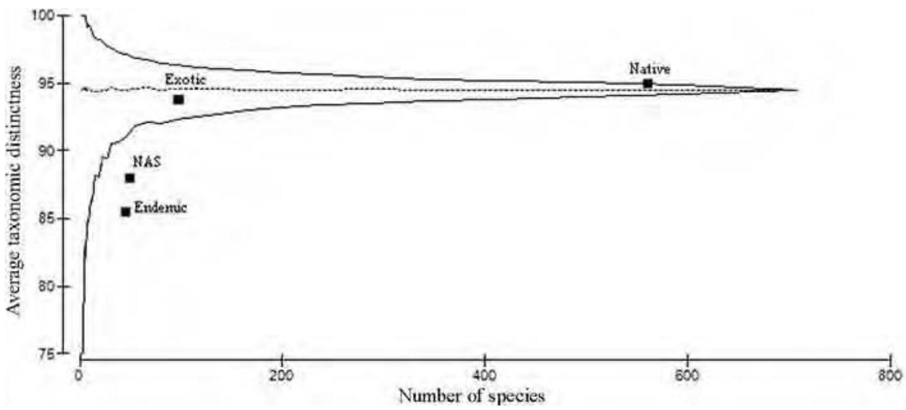

Fig. 2. Funnel plot for simulated average taxonomic distinctness AvTD for Mediterranean fishes based on a 3-level classification (species, families, orders). (N=707 species: master list taken from Froese and Pauli, 2008). The interrupted line denotes the simulated AvTD; continuous lines indicate the limits within which 95% of simulated TD values lie. The TD values calculated for the sub-groups of 'exotic', 'endemic', 'native' and north expanding species 'NES' are superimposed.

[4] If we consider 707 species to be the total number of fish species in the Mediterranean Sea (Froese and Pauly, 2008). Other Authors (Ben Rais Lasram and Mouillot, 2008) counted more than the 19%.

[5] Differently from the commonly used diversity indexes, *AvTD* is independent from the number of species.

seems to be reduced with respect to the mean Mediterranean value and this would reflect the importance of a few higher taxa (families such as Serranidae, Carangidae and orders such as Perciformes and Tetraodontiformes) in the process of northward expansion. We can also observe that AvTD of NES is higher with respect to endemic species and lower if compared with exotic species.

Visibly, the advance of thermophilic fishes is not confined to the Mediterranean Sea (McFarlane *et al.*, 2000; Perry *et al.*, 2005). Similar range extensions have been observed in the Atlantic European waters (e.g. Quéro *et al.*, 1996; 1998; Bañón *et al.*, 2002; Stebbing *et al.*, 2002; Brander *et al.*, 2003; Bañón, 2004), and in other regions of the northern and southern hemisphere (Parker and Dixon, 1998; Irigoyen *et al.*, 2005); were tropical and subtropical species are crossing their northernmost or southernmost limits, respectively. Particularly significant are those examples which involve the same taxa across different marine areas. This is the case of native species such as *E. marginatus, C. crysos, B. capriscus, Pseudocaranx dentex, Solea senegalensis, Sphyraena* spp. (Table 1 – see page 44) which have extended their distribution margins, in both Mediterranean and extra-mediterranean areas. These synchronous responses[6] strongly confirm the existence of a single overriding force in the ocean environment. The coherence of such poleward spreads across distant and different locations stresses, once again, the valve of these organisms as indicators of warming in the marine environment.

Every single distributional extension generates community changes at the local and regional levels. Since no species losses have been recorded in the Mediterranean, the advance of southerly species is probably augmenting the total number of species in the northern basin. Moreover, this pattern follows general predictions: fish species richness normally decreases with latitude (Macpherson and Duarte, 1994) and in temperate marine areas, a gain in species is expected as a consequence of climate warming (Hiddink and Hofstede, 2008). A decrease in the size of fish species with climate warming, has been also predicted, being fish species typically smaller at lower latitudes (Macpherson and Duarte, 1994).

The effects of climate change on the distribution patterns of Mediterranean faunas are thought to be more noticeable in population located at the geographic distribution limits of the species and in certain focal spots, especially in correspondence of transitional areas and biogeographic boundaries (Bianchi, 2007). In the Mediterranean a major transitional sector is the Sicily Channel, which separates the western from the eastern basin and may be regarded as a privileged observatory for biodiversity changes. In the course of the Mediterranean history, this area acted as a filter to the eastern advance of Atlantic fauna (Quignard and Tomasini, 2000) and, up to recent times, it has been considered the western frontier to Lessepsian migration (Por, 1990; Quignard and Tomasini, 2000, Golani *et al.*, 2002). As a matter of facts, this barrier is now showing an astonishing weakness, being ineffective to stop the spreading of both the Atlantic and Indo-Pacific fish species which ultimately are crossing the Channel from West to East and from East to West, respectively. Taking into account published information and available species lists (e.g. Bradai *et al.*, 2004; Bianchini and Ragonese, 2007), the number of exotic fishes currently recorded in this area is of 10 Lessepsians (*Upeneus moluccensis*, *Fistularia commersonii*, *Stephanolepis diaspros*, *Leiognathus klunzingeri*, *Etrumeus teres*, *Siganus luridus*, *Siganus rivulatus*, *Pempheris vanicolensis*, *Parexocoetus mento*, *Priacanthus hamrur*) and 12 Atlantic invaders (*Beryx splendens*, *Gephyroberyx darwinii*, *Pisodonophis semicinctus*, *Microchirus boscanion*, *Solea senegalensis*, *Chaunax suttkusi*, *Psenes pellucidus*, *Trachyscorpia cristulata chinata*, *Seriola rivoliana*, *Seriola fasciata*, *Seriola carpenteri* and the Tetraodontiform *Sphoeroides pachygaster*, recorded all over the Mediterranean in the last two decades[7]). This observation can be taken as a reinforced signal of change for the Mediterranean biogeography.

Methodological questions

Attempts to predict climate-change impacts on biodiversity have often relied on the 'species-climate envelope' (Pearson and Dawson, 2003). In such a context, projections of distributions under future climate change scenarios can be formulated on the basis of climatic variables that

[6] ...of different populations belonging to the same species.

[7] See Psomadakis *et al.* (2006) and references therein included.

limit the current geographical distribution of any given species. The major drawback of this approach is that many non-climatic forces can influence species distributions (Hampe, 2004) and this is particularly obvious for exotic species. In fact, when a new species enters a new environment, a "pletora" of variables linked to the invasion process may play a major role, influencing species dynamics and adding new layers of complexity[8]. A strong variability characterizes also native fishes with respect to environmental changes. For these reasons, caution must be used when dealing with single species or populations. Obviously, the collection of data at the community level is a more powerful tool to evaluate the consequences of climate warming.

Another difficulty that we encounter in extrapolating the effects of temperature on biotic communities is represented by spatial and temporal variability and, so far, only few studies have taken it into appropriate consideration. One of these (Sabatés *et al.*, 2006) clearly demonstrated a link between temperature and the abundance of *S. aurita*. Results also showed the successful reproduction of *S. aurita* in the North-West Mediterranean, where this clupeid has recently expanded its distribution. As a matter of fact, knowledge of the reproductive condition of individuals that occur in correspondence of their geographical borders or are found outside these limits, is an essential information in the study of thermophilic expanding species (Azzurro *et al.*, 2007c). Among them, several species that previously were thought not to reproduce on the north, like *T. pavo* and the dusky grouper *E. marginatus* (Sara and Ugolini, 2001; Francour *et al.*, 1994), are now naturalized in these areas and seasonal recruitment occurs.

The contemporary relevance of range dispersal events has raised our interest for organisms that are found outside of their geographical limits. Indeed the number of scientific notes or brief articles, commonly called 'presence' or 'biodiversity records', has significantly increased in recent years. The sum of these anecdotal evidences makes us aware about the existence of large scale processes of change in marine biodiversity but how are these 'unusual' fishes usually intercepted? And what are our possibilities of study? The discovery of an exotic fish species in the Mediterranean is usually a fortuitous, unplanned episode and we generally have to wait until these species are found by chance (Azzurro, in press). Certainly, we miss specific procedures to detect of these 'newcomers' and this seems to be is a rather general constrain in invasion biology (Wittenberg and Cock, 2001).

In one recent attempt to ameliorate our capability to monitor fish biodiversity changes, an experimental system of early detection was developed in the Pelagie islands (Azzurro, 2007; MonItaMal, 2008). The system was inspired by community-based actions (Cooper *et al.*, 2007), recently developed with the aim to engage a dispersed network of volunteers to assist in professional research. People who could notice 'unusual fishes' in the course of their activities, i.e. fishermen and divers, were involved on the basis of a simple advertisement campaign and personal interactions. Given the familiarity of fishermen with local species, no training on taxonomy was considered necessary and no blacklist was proposed. Researchers were employed to validate the reports and to evaluate the effectiveness of the experiment. At the end, fishermen were mainly engaged by personal interactions, and only few by simple media promotion. In any case, fishermen were particularly helpful, both for the high frequency of validated records and for providing voucher specimens, suitable for biological analyses.

This small experiment provided very valuable results to our purposes. 'Scientists cannot be everywhere' and volunteer participants gave us the possibility to multiply our eyes on the scene. Hopefully, this practice could extend our capacity of research at larger geographical and temporal scales. Future efforts will be directed to develop a strong cooperation with the fishery and recreational sectors and to expand community-based monitoring experiences at the international level.

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[8] Ecological and biological factors may generate species-specific responses that are typically difficult to foresee and may be often contradictory. For instance, the spread of an invasive species may occur after a long time lag (Sakai *et al.*, 2001) or even immediately after the propagules introduction - see the different cases of *S. luridus* and *F. commersonii* as examples of 'long time lag' and 'immediate dispersion', respectively (Azzurro and Andaloro, 2004; Azzurro *et al.*, 2006; Azzurro *et al.*, 2007b).

Table 1. A list of Mediterranean northward expanding fish species based on the relevant published records of the last 15 years. Species thought to be increasing in their abundances are marked with asterisks. Evidences older than 1993 are indicated with the symbol "◊".
Extra-Mediterranean records testifying northward expansion were also reported, when available.
Information about the species origin (IP Indo-Pacific; A Atlantic; N native), habitat and climatic affinity (Trp = Tropical; Sbt = Sub-tropical; Deep = Deep waters) is reported, according with Golani *et al.* (2002) and Froese and Pauli, 2008 (<www.fishbase.org>).

Family	Species	Origin	Climate	Habitat	Intra-Mediterranean sources	Extra-Mediterranean sources
Balistidae	*Balistes capriscus**	N	Sbt	Reef-associated	Dulčić *et al.*, 1997b; Bradai *et al.*, 2004	Bañón *et al.*, 2002
Belonidae	*Tylosurus acus imperialis*	N	Sbt	Pelagic	Bello, 1996	–
Blenniidae	*Parablennius pilicornis*	N	Sbt	Demersal	Riera *et al.*, 1995; Nieder *et al.*, 2000	–
	Scartella cristata	N	Trp	Reef-associated	Nieder *et al.*, 2000	–
Carangidae	*Campogramma glaycos*	N	Sbt	Benthopelagic	Dulčić *et al.*, 2003	–
	*Caranx crysos**	N	Sbt	Reef-associated	Bradai *et al.*, 2004	Swaby *et al.*, 1996; Bañón and Casas, 1997
	*Caranx ronchus**	N	Sbt	Benthopelagic	Bradai *et al.*, 2004	–
	Pseudocaranx dentex	N	Trp	Reef-associated	Azzurro, unpublished data	Fernández-Cordeiro and Bañón, 1997
	Trachinotus ovatus	N	Sbt	Pelagic	Dulčić *et al.*, 1997a	
Clupeidae	*Etrumeus teres**	IP	Sbt	Pelagic	Falautano *et al.*, 2007	–
	*Sardinella aurita**	N	Sbt	Reef-associated	Dulčić and Grbec, 2000; Sinovčić *et al.*, 2004; Tsikliras *et al.*, 2006; Sabatés *et al.*, 2006	–
Coryphaenidae	*Coryphaena hippurus*	N	Sbt	Pelagic	Dulčić, 1999	–
Dasyatidae	*Taeniura grabata*	N	Sbt	Demersal	Quignard and Tomasini, 2000	–
Exocoetidae	*Parexocoetus mento*	IP	Trp	Pelagic	Dulčić and Grbec, 2000	–
Fistularidae	*Fistularia petimba*	A	Trp	Reef-associated	–	Bañón and Sande, 2008
	Fistularia commersonii	IP	Trp	Reef-associated	Sánchez-Tocino *et al.*, 2007	–
Gempylidae	*Ruvettus pretiosus*	N	Sbt	Bathipelagic	Bettoso and Dulčić, 1999	–
Haemulidae	*Plector. mediterraneus*	N	Sbt	Demersal	Lipej *et al.*, 1996	–
	Pomadasys incisus ◊	N	Sbt	Demersal	Quignard and Tomasini, 2000	
Hemiramphidae	*Hemiramphus far*	IP	Sbt	Pelagic	Dulčić and Grbec, 2000	–
	Hemiramphus picarti ◊	N	Sbt	Benthopelagic	Quignard and Tomasini, 2000	
Istiophoridae	*Tetrapterus albidus*	N	Sbt	Pelagic	Quignard and Tomasini, 2000	–
Kyphosidae	*Kyphosus sectator*	N	Sbt	Reef-associated	–	Bañón, 2004
Labridae	*Thalassoma pavo*	N	Sbt	Reef-associated	Vacchi *et al.*, 1999; Guidetti, 2002; Guidetti *et al.*, 2002; Sara *et al.*, 2001; 2005	–
	Xyrichthys novacula	N	Sbt	Reef-associated	Dulčić and Pallaoro, 2001	–
Leiognathidae	*Leiognathus klunzingeri*	IP	Trp	Demersal	Dulčić and Pallaoro, 2002	–
Lobotidae	*Lobotes surinamensis* ◊	N	Sbt	Benthopelagic	Quignard and Tomasini, 2000	Fishkeeping, 2008; Contreras-Balderas *et al.*, 2003
Monacanthidae	*Stephanolepis diaspros*	IP	Trp	Demersal	Dulcic and Pallaoro, 2003; Bdioui *et al.*, 2004	–
Nomeidae	*Psenes pellucidus*	A	Deep	Bathidemersal	Quignard and Tomasini, 2000	–
Ophichthidae	*Pisodon. semicinctus*	A	Sbt	Demersal	Quignard and Tomasini, 2000; Ragonese and Giusto, 2000; Serena, 2001	Bañón *et al.*, 2002
Pomatomidae	*Pomatomus saltatrix*	N	Sbt	Pelagic	Dulčić *et al.*, 2000	Contreras-Balderas *et al.*, 2003
Scaridae	*Sparisoma cretense*	N	Sbt	Reef-associated	Guidetti and Boero, 2001, Dulčić and Pallaoro, 2001	–
Scorpaenidae	*Pontinus kuhli*	N	Deep	Bathidemersal	Riera *et al.*, 1995	–
Sebastidae	*Trachysc. cristulata ech.* ◊	A	Sbt	Demersal	Massuti *et al.*, 1993	
Serranidae	*Epinephelus aeneus*	N	Sbt	Demersal	Riera *et al.*, 1995; Dulčić *et al.*, 2006	–
	Epinephelus caninus	N	Sbt	Demersal	Quignard and Tomasini, 2000	–
	Epinephelus coioides	IP	Sbt	Reef-associated	Parenti and Bressi, 2001	–
	Epinephelus costae	N	Sbt	Reef-associated	Riera *et al.*, 1995	–
	Epinephelus marginatus	N	Sbt	Reef-associated	Francour *et al.*, 1994; Dulčić and Lipej, 1997; Zabala *et al.*, 1997	Irigoyen *et al.*, 2005
	Mycteroperca rubra	N	Sbt	Demersal	Quignard and Tomasini, 2000; Glamuzina *et al.*, 2002	–
Siganidae	*Siganus luridus*	IP	Sbt	Reef-associated	Azzurro and Andaloro, 2004; Castriota and Andaloro, 2005	–
	Siganus rivulatus	IP	Sbt	Reef-associated	Dulčić and Pallaoro, 2004	–
Soleidae	*Solea senegalensis*	A	Sbt	Demersal	Quignard and Tomasini, 2000	Bañón *et al.*, 2002
Sparidae	*Diplodus cervinus* ◊	N	Sbt	Reef-associated	Quignard and Tomasini, 2000	
	Pagrus auriga	N	Sbt	Benthopelagic	Quignard and Tomasini, 2000	–
Sphyraenidae	*Sphyraena chrysotaenia*	IP	Sbt	Pelagic	Pallaoro and Dulčić, 2001	–
	Sphyraena sphyraena	N	Sbt	Pelagic	–	Bañón and Garazo, 2006
	Sphyraena viridensis	N	Trp	Pelagic	Quignard and Tomasini, 2000, Dulčić and Soldo, 2004	–
Stromateidae	*Stromateus fiatola*	N	Sbt	Benthopelagic	Dulčić *et al.*, 2000	–
Tetraodontidae	*Lagocephalus sceleratus*	IP	Trp	Reef-associated	Kasapidis *et al.*, 2007	–
	Sphoeroides pachygaster	A	Sbt	Demersal	Psomadakis *et al.*, 2006	–

Final remarks

Large scale forces are reshuffling Mediterranean fish biodiversity and a growing body of evidence testifies to the coherence of these changes with the putative effects of climate warming. Nevertheless, the extent of this phenomenon remains in some way hidden, because of the sporadic nature of monitoring efforts and of difficulties in exploring appropriate spatial and temporal scales. So far, our knowledge of this process has been limited to the sum of causal observations. Hence we need new methodologies, suitable to deepen our capability to perceive this complex process of change. The northward advance of thermophilic fishes is one of the first, and maybe most detectable biotic response to climatic changes. From this perspective, presence/absence data resulting from community-based surveys may be added to the tools for monitoring climatic-induced changes of Mediterranean biota. This information will be helpful to analyze the rates of spread and for species-climate modeling. Nevertheless, transitional sectors of the Mediterranean and cold areas (which represent endemic hotspots), should be considered with special care, as the best places where to detect biodiversity changes and where to concentrate our monitoring activities.

Other effects of climate change will be addressed by examining the response of ‘cold water’ biota and by comparing the phenology (i.e. the timing of biological events) of key species along spatial and temporal scales. The discussion on these possibilities of study goes far beyond the purposes of this paper but deserves further attention.