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Seawater warming at the northern reach for southern species: Gulf of Genoa, NW Mediterranean

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Global warming is facilitating the poleward range expansion of plant and animal species. In the Mediterranean Sea, the concurrent temperature increase and abundance of (sub)tropical non-indigenous species (NIS) is leading to the so-called 'tropicalization' of the Mediterranean Sea, which is dramatically evident in the south-eastern sectors of the basin. At the same time, the colder north-western sectors of the basin have been said to undergo a process of 'meridionalization', that is the establishment of warm-water native species (WWN) previously restricted to the southern sectors. The Gulf of Genoa (Ligurian Sea) is the north-western reach for southern species of whatever origin in the Mediterranean. Recent (up to 2015) observations of NIS and WWN by diving have been collated to update previous similar inventories. In addition, the relative occurrences of both groups of southern species have been monitored by snorkelling between 2009 and 2015 in shallow rocky reefs at Genoa, and compared with the trend in air and sea surface temperatures. A total of 20 southern species (11 NIS and 9 WWN) was found. Two WWN (the zebra seabream Diplodus cervinus *and the parrotfish* Sparisoma cretense*) and three NIS (the SW Atlantic sponge* Paraleucilla magna*, the Red Sea polychaete* Branchiomma luctuosum*, and the amphi-American and amphi-Atlantic crab* Percnon gibbesi*) are new records for the Ligurian Sea, whereas juveniles of the Indo-Pacific bluespotted cornetfish* Fistularia commersonii *have been found for the first time. While temperature has kept on increasing for the whole period, with 2014 and 2015 being the warmest years since at least 1950, the number of WWN increased linearly, that of NIS increased exponentially, contradicting the idea of meridionalization and supporting that of tropicalization even in the northern sectors of the Mediterranean basin.*

Keywords: Seawater warming, range expansion, tropicalization, meridionalization, new records, Ligurian Sea

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INTRODUCTION

Climatic warming is a primary driver of change in ecosystems worldwide (Gruner *et al.*, 2017, and references therein). One of the predicted effects of the global increase of temperature is the poleward range expansion of plant and animal species, both on land and in the sea (Burrows *et al.*, 2011). In the world ocean, evidence of this phenomenon is accumulating especially for warm-temperate areas (Bianchi *et al.*, 1998; Vergés *et al.*, 2014; Kaimuddin *et al.*, 2016).

In the Mediterranean Sea, in particular, seawater warming (Shaltout & Omstedt, 2014) has even more dramatic effects, as it offers further scope to the spread of (sub)tropical non-indigenous species (NIS hereafter) coming from the Red Sea through the Suez Canal, a man-made seaway, or from the Atlantic through the Straits of Gibraltar, a natural seaway (Bianchi & Morri, 2003). The concurrent temperature increase and abundance of (sub)tropical species is leading to the so-called 'tropicalization' of the Mediterranean Sea, which is dramatically obvious in the south-eastern sectors of the basin. At the same time, the colder northern sectors of the basin have been said to undergo a process of 'meridionalization' (Boero *et al.*, 2008, and references therein), that is the arrival of warm-water natives (WWN hereafter) previously restricted to the southern sectors. Coll *et al.* (2010) followed Boero *et al.* (2008) in considering tropicalization and meridionalization as two distinct processes. Bianchi (2007) observed that the patterns of distribution change are similar for all warm-water species, whether recently introduced in or native to the Mediterranean, and are governed by the same climatic, hydrological and ecological factors. Historically, the February surface isotherms of 15 and 14°C acted as the 'divides' between a warmer and a colder water biota within the Mediterranean. In particular, the 15°C isotherm set the limit for the tropical species, whereas the 14°C isotherm set the limit for the native warm-water species (Bianchi *et al.*, 2012). However, since the mid 1980s, when the Mediterranean seawater warming became evident, many 'southerners', either NIS or WWN, started crossing these divides to colonize even the northern reaches of the Mediterranean Sea (Bianchi, 2007).

The Ligurian Sea, located in the north-western Mediterranean, is one of the coldest sectors of the basin:

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accordingly, its biota is nearly deprived of (sub)tropical elements (Bianchi & Morri, 2000). Finding southern species, however, has become comparatively frequent in the last decades (Parravicini *et al.*, 2015, and references therein). All these records, however, derive from occasional observations made irregularly while diving for research not especially devoted to the occurrence of southern species: no specific monitoring programme has ever been implemented, and time data series are almost non-existent (Bianchi, 2001).

Besides updating the occasional records of southern species sighted by diving in the Ligurian Sea, this paper aims at presenting the results of the first monitoring activity purposely dedicated to the inventory of southerners, either WWN or NIS. Southerners' occurrences will be discussed in relation with temperature data, under the hypothesis that, should the difference between meridionalization and tropicalization be tenable, colonization by WWN will be more important than that by NIS.

MATERIALS AND METHODS

Study area

The area of study corresponds to the wider Gulf of Genoa, located in the northernmost part of the Ligurian Sea, from the French border to the west to the boundary with Tuscany to the east. If the 'sub-Atlantic' northern Adriatic, where the Mediterranean influence is reduced (Sacchi *et al.*, 1985), is excluded, the Ligurian Sea represents the northernmost reach for southern species in the Mediterranean Sea. Locations of this kind, where no further range expansion is possible for poleward moving species, have been called 'range termini' (Canning-Clode & Carlton, 2017).

The coasts of the Ligurian Sea are among the most urbanized and industrialized of Italy (Morri & Bianchi, 2001) but nevertheless host a number of Marine Protected Areas and Sites of Community Interest because of their importance for biodiversity conservation (Cattaneo-Vietti *et al.*, 2010; Parravicini *et al.*, 2013). We compiled the recent records of southern species from various kinds of survey carried out by scuba diving mostly in those localities, and in particular (from west to east) in Ventimiglia, Gallinara Island, Borgio Verezzi, Bergeggi, Genoa, Portofino, Sestri Levante, Monterosso and La Spezia (Figure 1A). Species collected by sampling, with fishery, on fouling panels, or from ship hulls, and inconspicuous species found in these or other sites were not considered, as our study does not aim at a full review of all the southern species recorded from the area but just at analysing a homogeneous list of a subset of conspicuous species that had been sighted by diving.

Fig. 1. Study area. (A) the wider Gulf of Genoa in the Ligurian Sea (NW Mediterranean), with the localities where southern species have been occasionally recorded by diving in recent years. (B) Lido and Quarto, the two monitoring locales of Genoa, 2009–2015.

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Purpose-done monitoring has been carried out by snorkelling in two locales of Genoa city, about 2 km from each other: Lido (44°23′21.20″N 8°58′06.50″E) and Quarto (44°23′25.69″N 8°59′22.39″E) (Figure 1B).

Field methods

The occasional records taken into account come exclusively from ecological surveys using scuba diving. Dives consisted of depth transects (Bianchi *et al.*, 2004), i.e. transects deployed perpendicularly to the coastline from the water surface down to 30+ m depth. During each dive, WWN and NIS were visually identified and their depth and habitat of occurrence were noted. Only conspicuous species, easily recognizable in the field, were considered; voucher specimens were collected only in cases of doubt. Recent data (up to 2015) have been collated to update previously existing inventories (Bianchi & Morri, 1993; Bianchi *et al.*, 2011; Parravicini *et al.*, 2015; and references therein), and the resulting information was reorganized by 5-year periods in order to investigate potential time trends. Given the different goals of the surveys and the inhomogeneity of data available, no careful estimation of the sampling effort can be done, and interannual comparison needs to be taken with caution.

On the contrary, the finding of southern species during the monitoring activities at Genoa has been made purposely with a standardized protocol for 7 years (2009–2015 included). Species were inventoried by snorkelling in shallow (0 to about 3 m depth) rocky reefs in both Lido and Quarto, spending about 2 h per week from June to September. Species occurrences, together with other observations, were annotated on a diving slate, collection of specimens being done only when necessary to check species identity.

Temperature data

Sea surface temperature (SST) was derived from NOAA satellite data at 42°54′N and 9°24′E (freely available at www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl), calibrated with the available field measurements (Bianchi & Morri, 2004a). Despite calibration, these data must be considered as representative mostly of offshore conditions. In shallow coastal waters, air temperature data are often better climatic proxies than ocean temperature data (Morri & Bianchi, 2001). Thus, we also used the annual means of air temperature for the last five decades obtained from the Meteorological Observatory of Genoa.

RESULTS

Update of occasional records

Recent surveys in the wider Gulf of Genoa recorded 18 southern species, viz. 9 WWN and 9 NIS (Table 1). Among the WWN, all but *Diplodus cervinus* and *Sparisoma cretense* had already been found previously. Regarding *D. cervinus*, a subadult of 20 cm was observed on a shallow rocky shoal at Vesima (a locale of Genoa) in August 2008 and a juvenile at Lido in August 2011; through summer 2015, pairs or small shoals of large adults have been a common sight around the islands of Gallinara and Bergeggi. Regarding *S. cretense*, a single male of 22 cm was observed in June 2015 at Ventimiglia, close to the French border. In the case of *Sphyraena viridensis* and *Thalassoma pavo*, finding juveniles through the years in multiple localities has been frequent.

Among the NIS, four species come from the Atlantic Ocean, two from the Pacific, one from the Indian (Red Sea), and one is circumtropical (Table 1). *Paraleucilla magna* (Figure 3C) and *Branchiomma luctuosum* (Figure 3E) are new records for the Ligurian Sea. *Amathia verticillata* (Figure 3F) was found for the first time outside harbours in 2000.

Collating this information from recent surveys with similar occasional records by scuba diving already published in previous years, indicates that WWN tend to overnumber NIS (Figure 2). However, the number of WWN somehow fluctuated with time, with a minimum between the mid 1960s and the early 1980s, while that of NIS increased more steadily, with an apparent acceleration after the 2000s.

Monitoring

Monitoring by snorkelling at Genoa between 2009 and 2015 allowed inventorying 18 southern species, viz. 8 WWN and 10 NIS (Table 1, Figure 3). All the WWN but *D. cervinus* were already known for the Ligurian Sea. *Thalassoma pavo* was comparatively abundant, and terminal phase males were always observed towards the end of the summer at Lido. Also *S. viridensis* was a constant presence, with juveniles growing from 8 cm in June to 12+ cm in September at Quarto. In 2015 at Lido, a school of individuals about 20 cm long (Figure 3B) was characterized by a yellow tail that was reminiscent of *Sphyraena flavicauda* Rüppell, a Lessepsian migrant reported from Israel and Turkey but not yet from the Western Mediterranean. However, the respective position of the dorsal, pectoral and pelvic fins and the presence of a dark edge on the sides of the caudal fin gave evidence in favour of *S. viridensis*.

As for the NIS, five species come from the Atlantic, two from the Indian, two from the Pacific, and one is circumtropical (Table 1). *Percnon gibbesi* (Figure 3A) is a new record for the Gulf of Genoa and the northernmost record for the Mediterranean. The small population observed at Lido in 2015 included juveniles and females; at Quarto in 2015, we observed males fighting (Figure 4), which is possibly indicative of sexual activity, but no pregnant females. Juveniles (about 10 cm) of *F. commersonii* (Figure 3D) were observed for the first time in the Ligurian Sea at Quarto in 2015.

The number of both WWN and NIS increased with time between 2009 and 2015, but the increase was tendentially linear for the former and exponential for the latter (Figure 5).

Comparison with temperature data

Both air temperature at Genoa and Ligurian Sea surface temperature raised in the last decades, average temperatures in the last years being up to half a degree higher than in the 1970s (Figure 6). However, the rise of temperature was not regular with time. Notwithstanding large year-to-year variability, four main phases can be distinguished in both air and sea surface temperature trends (Figure 6): (1) a comparatively cold phase from the late 1960s to the early 1980s; (2) a rapid warming in the second half of the 1980s; (3) a warmer, stabilized phase since the 1990s; (4) another rapid temperature rise in the last few years. At present, the fourth

Table 1. New records of southern species (either NIS or WWN) by diving in the Gulf of Genoa, including the results of monitoring by snorkelling in the Genoa locales (Lido and Quarto) and further unpublished information from other Ligurian localities (Ventimiglia, Gallinara Island, Borgio Verezzi, Bergeggi, Genoa, Portofino, Sestri Levante, Monterosso, and La Spezia).

Phylum, species	NIS or WWN	Native range	Genoa monitoring	Other unpublished Ligurian Sea records
Rhodophyta				
Acrothamnion preissii (Sonder) E.M. Wollaston	NIS	Tropical and warm-temperate Pacific Ocean	Lido, 2013–2015	Monterosso, 1998, *Posidonia oceanica* rhizomes, 18 m
Tricleocarpa fragilis (Linnaeus) Huisman and R.A. Townsend	WWN	Circumtropical	Lido, 2012–2014	Gallinara, 1991, 2009, rocks, 8–15 m; Bergeggi, 2003, 2005, 2009, rock, 5–10 m, abundant; Portofino, 2001, 2003, 2008, 2009, rock, 5–10 m; Sestri Levante, 1993, 2005, 2006, rock, 6 m; Monterosso, 1996, rock, 9 m
Dinoflagellata				
Ostreopsis ovata Fukuyo	NIS	Circumtropical	Lido, 2014, 2015; Quarto, 2014, 2015, on *Halopteris scoparia*	Portofino, 2001, rock, 1 m, on *Perforatus perforatus*; Quarto, 2003, 2005, 2006, 0.5 m, rock, on *Ellisolandia elongata*
Chlorophyta				
Anadyomene stellata (Wulfen) C. Agardh	WWN	Circumtropical	Lido, 2011	Gallinara, 2009, rock, 4 m; Borgio Verezzi, 2004, beach-rock, 3 m; Sestri Levante, 1997, rocks, <1 m
Caulerpa cylindracea Sonder	NIS	W Australia	Lido, 2009–2015, very abundant in 2012 and 2013; Quarto, 2011, 2014 (abundant), 2015	Gallinara, 2009, 12–20 m, on dead *Posidonia oceanica* matte; Bergeggi: 2004, 2005, 2009, 11–33 m, abundant on dead *Posidonia oceanica* matte, within *Cymodocea nodosa* meadow, on pebbles and biodetritic sand; Quarto, 2000, 2003, 2006, rock, 0–2 m, abundant; Portofino, 2008, 2009, 2013, 2015, rock and pebbles, common, 6–33 m; Sestri Levante, 2008, rock, 5 m; Monterosso, 2008, rock, 18–26 m, abundant
Porifera				
Paraleucilla magna Klautau, Monteiro and Borojevic	NIS	Tropical SW Atlantic	Lido, 2012, 2015; Quarto, 2015	Portofino, 2013, seamark, 12 m
Cnidaria				
Oculina patagonica De Angelis	NIS	SW Atlantic		Bergeggi Isle, 1995, 1996, 2003, rock, 0.5 m; Borgio Verezzi, 2004, beach-rock, 3 m; Capo Noli (near Bergeggi), 2005, rock, 5 m; Gallinara, 2009, rock, 4 m
Pennaria disticha Goldfuss	WWN	Circumtropical	Lido, 2013–2015; Quarto, 2015	Bergeggi, 2004, rock, 8 m; Portofino, 1993, 2004, 2005, rock, 3 m; Sestri Levante, 2008, 6 m; Monterosso, 1995, 2000, 2008, rock, 3–10 m; La Spezia, 1990, 1993, 2001, 2007, rock, artificial substratum, 3–6 m
Ctenophora				
Mnemiopsis leidyi A. Agassiz	NIS	NW Atlantic	Lido, 2014, 2015	Genoa, 2003, 2009; La Spezia, 2009
Annelida				
Branchiomma luctuosum (Grube)	NIS	Red Sea	Lido, 2011, 2012, 2014, 2015	La Spezia, 1989, 1991, 2010, rock and *Posidonia oceanica* matte, 2–5 m
Arthropoda				
Calcinus tubularis (Linnaeus)	WWN	NE Atlantic	Lido, 2015, in a tube of *Protula tubularia*	Gallinara, 1992, 3 m, in a vermetid tube
Percnon gibbesi (H. Milne Edwards)	NIS	Tropical amphi-American and amphi-Atlantic	Lido, 2015, including juveniles; Quarto, 2015	
Bryozoa				
Amathia verticillata (delle Chiaje)	NIS	Tropical W Atlantic	Lido, 2013, 2015; Quarto, 2015, abundant during the first half of July	Sestri Levante, 2000, rock, 0.5–3 m; La Spezia, 2001, on *Mytilus galloprovincialis* farm structures, 1–3 m
Chordata				
Diplodus cervinus (Lowe)	WWN	Subtropical E Atlantic	Lido, 2011, juvenile	Genoa, 2008, rock, 2 m; Bergeggi, 2015, 12 m; Gallinara, 2015, 17 m

Continued

Table 1. Continued

Phylum, species	NIS or WWN	Native range	Genoa monitoring	Other unpublished Ligurian Sea records
Fistularia commersonii Rüppell	NIS	Indopacific	Quarto, 2015, juveniles	
Parablennius pilicornis (Cuvier)	NIS[a]	(Sub)tropical Amphi-Atlantic	Lido, 2010–2015	Bergeggi, 2005, rock, 0.5 m; Sestri Levante, 2008, rock, 0.5 m; Monterosso, 2009, rock, 0.5 m
Scartella cristata (Linnaeus)	WWN	Circumtropical	Lido, 2009–2015	Genoa, 1984, 1989, 1990, 2008, rock, 0.5 m; Sestri Levante, 2008, rock, 0.5 m
Sparisoma cretense (Linnaeus)	WWN	(Sub)tropical E Atlantic		Ventimiglia, 2015, rock, 18 m
Sphyraena viridensis Cuvier	WWN	(Sub)tropical E Atlantic	Lido, 2010–2015, juveniles; Quarto, 2011, 2014, 2015, juveniles	Portofino, 2000, 2015, 10 m; Sestri Levante, 1997, 2000, 1 m, juveniles; Monterosso, 2008, 15 m
Thalassoma pavo (Linnaeus)	WWN	(Sub)tropical E Atlantic	Lido, 2009–2015, about 10 individuals with 1–2 terminal phase males; Quarto, 2013, 2015	Gallinara, 1992, 2009, 3–4 m; Bergeggi, 1995–2005, 3 m; Quarto, 1995, 2000, 2001, 2 m; Portofino 1993, 1995, 2000, 2001, 2003 (juveniles), 2008, 2009, 2013, 2015, 1–13 m; Sestri Levante, 1997, 2000, 2009, 1–2 m; Monterosso, 1995 (juvenile), 2000, 2005, 3–5 m

[a] The origin of this species is controversial (see Evans *et al*., 2015, for a critical commentary). Here we follow Pastor & Francour (2010) who consider it as non-indigenous species.

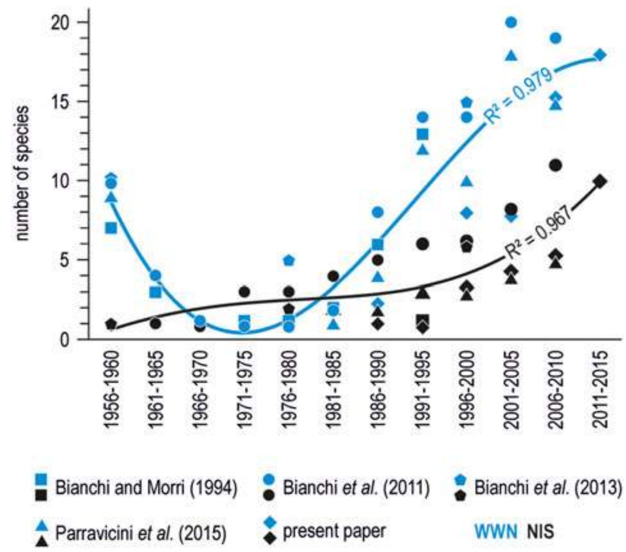

Fig. 2. Number of southern species (either WWN or NIS) recorded by diving in the wider Gulf of Genoa per 5-year period, according to various sources (Bianchi & Morri, 1994; Bianchi *et al*., 2011, 2013; Parravicini *et al*., 2015). The curves represent the second degree polynomial fits of mean data points for either WWN or NIS.

phase may only be guessed, and further measurements through the years to come will be necessary to confirm or contradict this hypothesis.

Focussing on this last period of apparent rapid warming, and considering only the information from Genoa monitoring (more reliable than the occasional records), the total number of southern species is positively related to sea surface temperature (Figure 7A). However, the NIS-to-WWN ratio is also positively related to sea surface temperature, suggesting that warming is actually favouring NIS more than WWN (Figure 7B).

DISCUSSION

Collating occasional records by scuba diving from various localities of the wider Gulf of Genoa and purposely monitoring by snorkelling for 7 years (2009–2015) at two Genoa city locales (Lido and Quarto) led to a total of 20 southern species (11 NIS and 9 WWN), and allowed adding five species to the lists available in previous publications (Bianchi & Morri, 1993, 1994; Cattaneo-Vietti *et al*., 2010; Occhipinti-Ambrogi *et al*., 2011; Parravicini *et al*., 2015; and references therein).

Two of these new records concern native species, namely the fishes *Diplodus cervinus* and *Sparisoma cretense*. Of the former, both juveniles and adults have been observed; of the latter, only one subadult. Juveniles of *S. cretense* have been recently seen in the French part of the Ligurian Sea (Astruch *et al*., 2016). Comparable northward range expansions of this species in other areas (Dulčić & Pallaoro, 2001; Guidetti & Boero, 2001; Abecasis *et al*., 2008; Perdikaris *et al*., 2012; Gambi *et al*., 2016; Yapici *et al*., 2016) suggest a general ongoing process. *Sparisoma cretense* is one of the best know examples of a disjunct Atlantic-Levantine distribution (Bianchi *et al*., 2012). Should the present trend persist, the Atlantic Ocean and Levant Sea populations, which have been

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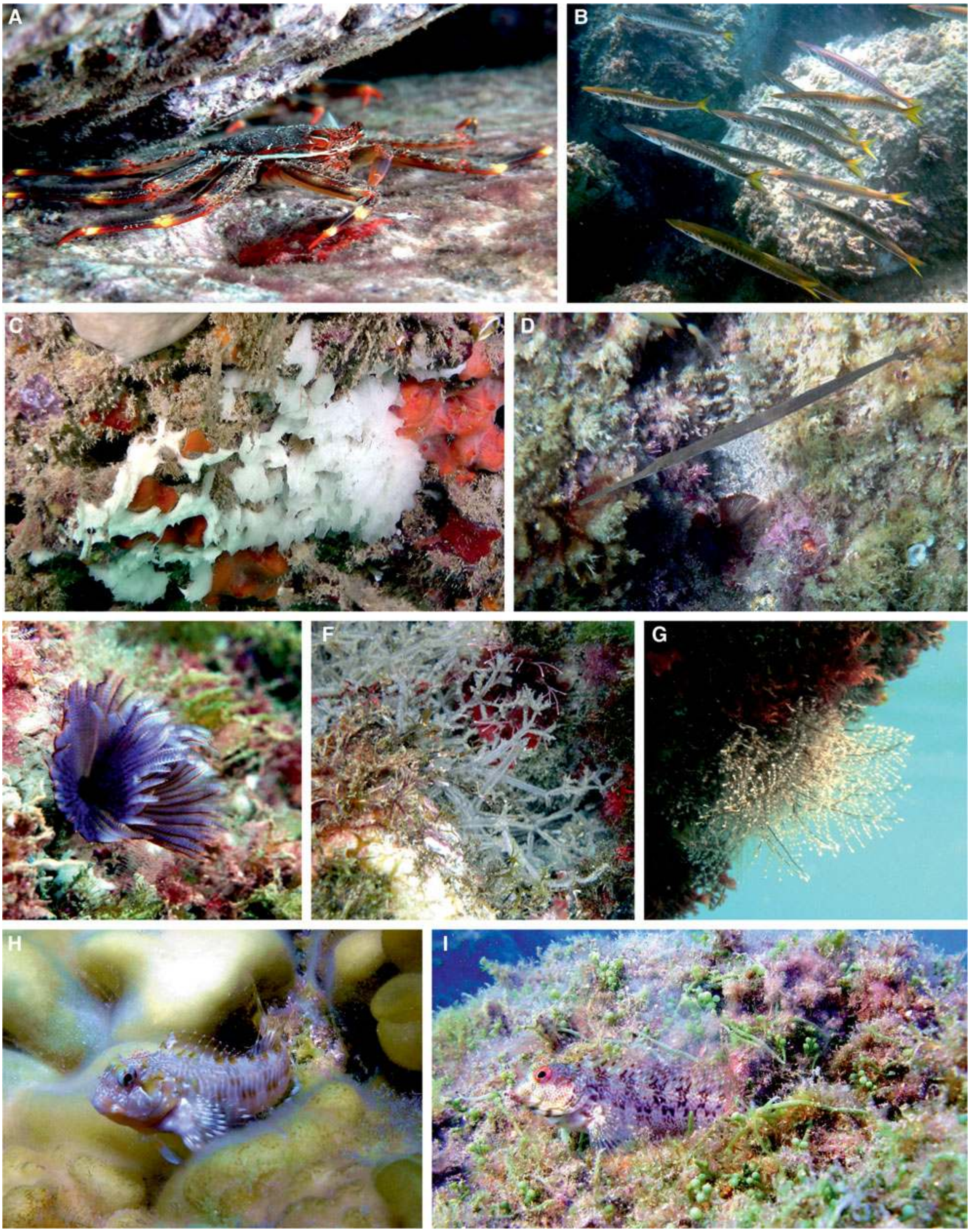

Fig. 3. Selected examples of southern species (either WWN or NIS) found in the Genoa monitoring locales: (A) *Percnon gibbesi*; (B) *Sphyraena viridensis*; (C) *Paraleucilla magna*; (D) *Fistularia commersonii*, juvenile; (E) *Branchiomma luctuosum*; (F) *Amathia verticillata*; (G) *Pennaria disticha*; (H) *Scartella cristata*, juvenile; (I) *Parablennius pilicornis*, amid *Caulerpa cylindracea*.

separated since the last interglacial, will merge again in the future.

The other three new records correspond to NIS: the SW Atlantic sponge *Paraleucilla magna*, the Red Sea polychaete *Branchiomma luctuosum*, and the amphi-American and amphi-Atlantic crab *Percnon gibbesi*. These NIS have been found on artificial substrates and/or in degraded habitats, confirming their greater susceptibility to invasion

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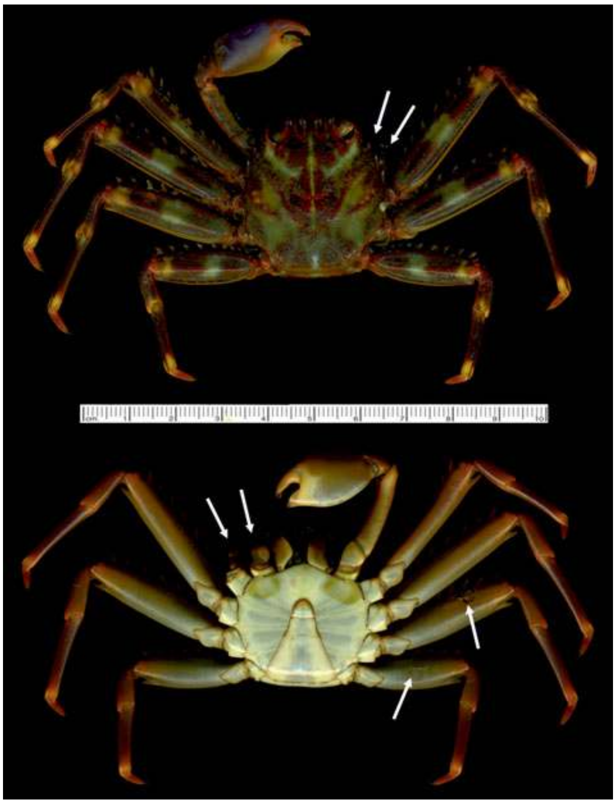

Fig. 4. A male specimen of *Percnon gibbesi* mutilated and wounded (arrows) during a fight with another male at Quarto, August 2015.

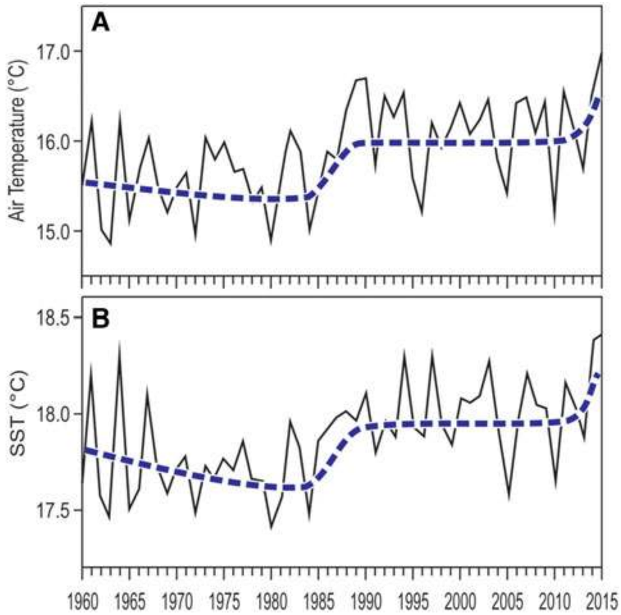

Fig. 6. Temperature yearly averages, 1960–2015. (A) air temperature, from the Meteorological Observatory of Genoa University. (B) sea surface temperature (SST), from NOAA satellite data (http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl). In both cases, the smoothed and broken thick line depicts the 11-year moving average.

(Occhipinti-Ambrogi *et al.*, 2011). *Paraleucilla magna* was first recorded on an offshore seamark bearing hydrophones installed in the Marine Protected Area of Portofino to monitor dolphin activity (Brunoldi *et al.*, 2016). In the Tyrrhenian Sea, it similarly occurs mostly on artificial structures (Gambi *et al.*, 2016). *Branchiomma luctuosum* was first recorded in a degraded seagrass meadow and on artificial reefs in the Gulf of La Spezia in 1989 and 1991, and then was not found again until reappearing on artificial reefs at Genoa more than 20 years later. The same erratic behaviour is apparently shown in the Tyrrhenian Sea (Gambi *et al.*, 2016). The branchial crowns of the specimens seen in the Gulf of Genoa displayed two different colour varieties (Figure 3E): brown (more frequent at Genoa) and purple (more frequent at La Spezia). The first individuals of *P. gibbesi* have been observed in August 2015 amidst the

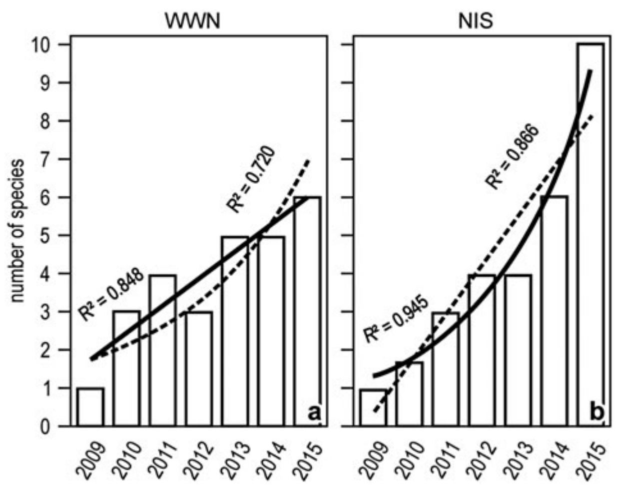

Fig. 5. Yearly trends in the number of WWN (A) or NIS (B) in the Genoa monitoring locales. Linear and exponential fits are superimposed, with solid lines indicating the best fit.

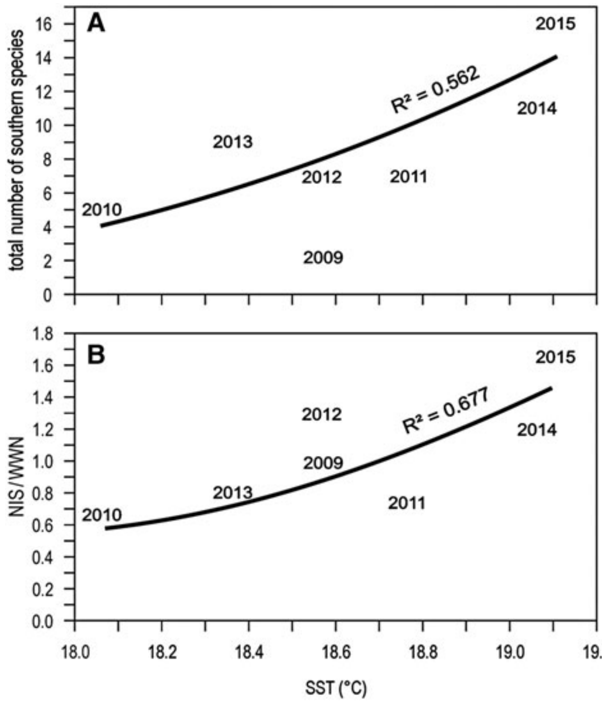

Fig. 7. Relationships between the total number of southern species (A) or the NIS-to-WWN ratio (B) found in the Genoa monitoring locales and sea surface temperature (SST). The exponential curves represent the best fit.

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blocks of artificial reefs at Genoa (Figure 3A), a preferred substrate for the larvae of this species to settle (Zenone *et al.*, 2016).

The Indo-Pacific fish *Fistularia commersonii* was already known for the Ligurian Sea (Garibaldi & Relini-Orsi, 2008; Occhipinti-Ambrogi & Galil, 2008), but only as adults; juveniles were first observed in 2015 at Genoa (Figure 3D), which also constitutes the northernmost record for the species. Juveniles have also been observed for many other southern species (either WWN or NIS), and this might suggest their naturalization in the northern Gulf of Genoa. Mating and established populations there have been documented, for example, in the case of the native thermophilic fish *Thalassoma pavo* (Vacchi *et al.*, 1999, 2001; Sara *et al.*, 2005).

Most of the species recorded are now widespread in the wider Gulf of Genoa, although not all reach the densities commonly observed in the Southern Mediterranean (e.g. Guidetti *et al.*, 2002). NIS, in particular, after the initial colonization in anthropized habitats, have recently also occupied natural habitats. The bryozoan *Amathia verticillata*, known for a long time as restricted to harbours (Geraci & Relini, 1970), has been observed off open coasts since at least 2000, in agreement with records from southern Mediterranean localities (Galil & Gevili, 2014; Gambi *et al.*, 2016). The fish *Parablennius pilicornis* is now common in the artificial reefs of the wider Gulf of Genoa, and its settling on natural reefs is facilitated by human impacts (Parravicini *et al.*, 2008, and references therein). The green alga *Caulerpa cylindracea*, first recorded in the Gulf of Genoa in the 1990s (Modena *et al.*, 2000, and references therein), is now common in various coastal habitats, from the sea surface to 40+ m of depth, thus contributing to the biotic homogenization of Ligurian Sea ecosystems (Montefalcone *et al.*, 2015).

Recent experiences in the Southern Mediterranean showed that *C. cylindracea* provided the largest contribution to the diet of *P. gibbesi* (Marić *et al.*, 2016). Should that be true also for the Gulf of Genoa, it would raise two contrasting hypotheses: (i) the present abundance and commonness of *C. cylindracea* will facilitate the spread of *P. gibbesi* to other habitats; (ii) the establishment of *P. gibbesi* will control the abundance of *C. cylindracea*, at least at shallow depth. Further studies might elucidate these two possibilities, which perhaps might not be mutually exclusive.

There is a striking coincidence between the increase in air and sea surface temperatures and the increase in the number of records of southern species in the Gulf of Genoa. A link between seawater warming and the entry of tropical species has been demonstrated in the Eastern Mediterranean (Raitsos *et al.*, 2010; Mavruk *et al.*, 2017), and the results of the present study suggest this holds true for the wider Gulf of Genoa, considering all warm-water species, either natives or NIS. Of course, it is not the temperature *per se* that facilitates the arrival of southern species, which may instead be favoured by changing current patterns (Gaylord & Gaines, 2000; Booth *et al.*, 2007; Wilson *et al.*, 2016). This is particularly true in the case of WWN (Astraldi *et al.*, 1995), whereas in the case of NIS transport on ship hulls or ballast waters and other anthropogenic vectors play a major role (Zenetos *et al.*, 2012). However, higher temperatures are obviously instrumental to the establishment success of warm-water species (Mieszkowska *et al.*, 2006), as confirmed by the positive relation found in Genoa monitoring data.

Temperature increase in the Gulf of Genoa has not been regular: rather, several phases could be distinguished (Parravicini *et al.*, 2015; Gatti *et al.*, 2017). Occasional records indicate a decreased richness of WWN, but not of NIS, during the comparatively cold phase of the 1970s. The rapid warming phase of the 1980–1990s caused mass mortalities in many autochthonous organisms (Cerrano *et al.*, 2000; Lejeusne *et al.*, 2010), which were often replaced by NIS causing phase shift in the communities involved (Montefalcone *et al.*, 2007; Gatti *et al.*, 2015). Other autochthonous species found refuge at depth (Puce *et al.*, 2009; Gatti *et al.*, 2017). Warm-water species have been seen to increase along a south-north gradient (Azzurro *et al.*, 2011) and to outcompete, where abundant, their cool-water relatives, causing depth distribution shifts (Milazzo *et al.*, 2016). It is too early to tell whether the high temperatures measured in the last 2 years are indicative of a further phase of rapid warming (Shaltout & Omstedt, 2014). However, new events of mass mortality have been observed in the Western Mediterranean Sea in late summer 2015 (Rubio-Portillo *et al.*, 2016) and a new wave of southern species established in summer 2015 in the Gulf of Genoa, their northernmost reach in the Western Mediterranean.

CONCLUSIONS

Occasional records by diving suggest that today (2015) native WWN are as numerous as NIS (nine species each) in the Gulf of Genoa. Presence-only records have been demonstrated adequate for modelling the niche of invasive species (Raybaud *et al.*, 2015), but due to their inherent inhomogeneity such data should always be taken with caution. Lack of time data series (which may also validate the reliability of models) remains a major problem when investigating the biological response to climate change in the Mediterranean Sea (Bianchi, 1997; Bianchi & Morri, 2004b). Regular Genoa monitoring by snorkelling in the last 7 years inventoried fewer WWN than NIS (8 *vs* 10). In addition, and more importantly, the number of the WWN increased linearly, that of the NIS increased exponentially.

These results provide little support to the idea of meridionalization of the northern sectors of the Mediterranean Sea. In our opinion, the process of tropicalization also concerns the northern Mediterranean, where it is simply less showy: so far, tropical NIS remain few when compared to what is observed in the southern sectors (e.g. Pancucci-Papadopoulou *et al.*, 2012; Evans *et al.*, 2015; Mannino *et al.*, 2016; Turan *et al.*, 2016). This notwithstanding, the northern Ligurian Sea is one of the areas most impacted by NIS in the Mediterranean Sea (Katsanevakis *et al.*, 2016). Occhipinti-Ambrogi *et al.* (2011) listed 38 species for the Italian part of the Ligurian Sea, roughly corresponding to our wider Gulf of Genoa.

The results of Genoa monitoring seem to support the idea of Bianchi (2007) that meridionalization and tropicalization are not two distinct processes, as affirmed by Boero *et al.* (2008). Rather, they are an expression of the same phenomenon of poleward range extension that is occurring globally. We also raise doubts about the semantic distinction between the two terms. Both southerners (WWN and NIS) are mostly comprised of eurythermal tropical species that are able to expand their range into warm temperate seas (as the Mediterranean is) during warmer climatic phases (Briggs, 1974). Surely, the penetration into the Mediterranean of Red Sea species through the Suez Canal is a new phenomenon caused by the artificial cut of a new seaway between two seas that had been separated for 10 million years (Galil, 2006). Once in the Mediterranean, however, these Red Sea species expand their range northward in the same way as the NIS coming from the Atlantic and the WWN. The cases of *Percnon gibbesi* and *Fistularia commersonii* are paradigmatic: the former species came from the Atlantic, the latter from the Indopacific, but adding the present records to the maps published by Katsanevakis *et al.* (2011) and Azzurro *et al.* (2013), respectively, their distributions within the Mediterranean are today identical. If we drop the distinction NIS/WWN in favour of a tropical/warm-temperate one, the 18 species found during Genoa monitoring include 12 tropical *vs* six warm-temperate species (Table 1), thus reinforcing the idea that the Gulf of Genoa is getting tropicalized rather than meridionalized. To complicate the picture, the Genoa NIS also include some warm-temperate species, such as the green alga *Caulerpa cylindracea* and the combjelly *Mnemiopsis leidyi*. Another complication arises from the fact that species having previously been considered natives to the Mediterranean have recently been revealed to be NIS, such as for instance the fish *Parablennius pilicornis* (Pastor & Francour, 2010; but see also Evans *et al.*, 2015), the bryozoan *Amathia verticillata* (Marchini *et al.*, 2015), and perhaps the hydroid *Pennaria disticha* (González-Duarte *et al.*, 2016). Finally, the word 'meridionalization' itself may sound ambiguous: to native speakers of Latin languages, who coined it, it recalls the South ('meridional' meaning 'southern') but in English it may recall the meridians, and thus confound the native English speaking reader. Everybody gets what tropicalization and poleward spread mean, while meridionalization may be understood by Mediterranean workers only. In other regions of the NE Atlantic where poleward range extension of marine species is being studied, only the word tropicalization is used, while meridionalization is not (Kaimuddin *et al.*, 2016). Montero-Serra *et al.* (2015) introduced the term 'subtropicalization' as an apparent equivalent of meridionalization. Poleward spread of low-latitude species is similarly observed in the southern hemisphere (Marzloff *et al.*, 2016): there, such species came from the North, not from the South: should we thus speak of 'septentrionalization' ('septentrional' meaning 'northern')? Tropicalization, meridionalization, subtropicalization and septentrionalization represent a cumbersome and pointless proliferation of terms to describe the same ecological phenomenon: the establishment of warm-water species of whatever origin in areas outside their original range due to climate warming (Canning-Clode & Carlton, 2017).

Should the present seawater warming continue in the future, the Mediterranean would undergo a generalized process of biotic homogenization, and the well established differentiation among its distinctive sub-basins would probably fade away (Bianchi *et al.*, 2013). A different pattern of change in the southern and northern basins (i.e. tropicalization *vs* meridionalization) should not be expected: rather, a smooth gradient in a south-north direction will take place (Bianchi, 2007). To understand and manage these changes, the organization of occasional presence-only records into structured datasets will of course remain important for quantifying species range shifts (Yalcin & Leroux, 2017) but will not be sufficient without monitoring (Lee *et al.*, 2008; Otero *et al.*, 2013): implementing networks of sustained monitoring activities should be a major concern for scientists and environmental managers alike.

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