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ORIGINAL ARTICLE

A multidisciplinary study on the effects of climate change in the northern Adriatic Sea and the Marche region (central Italy)

F. Appiotti · M. Krželj · A. Russo · M. Ferretti · M. Bastianini · F. Marincioni

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Abstract An integrated analysis of recent climate change (including atmosphere, sea and land), and social reaction and adaptation, was conducted in central Italy and the northern portion of the Adriatic Sea. The collected environmental data included meteorological, oceanographic, and river gauges stations, covering the time period 1961–2009. Social data included 800 questionnaires and interviews carried out on selected samples of residents, decision-makers, and emergency managers. The trend analysis of air temperature data detailed an overall increase in all seasons, whereas rainfall data showed decrease in winter, spring, and summer, and increase in autumn, influencing river flow changes. Marine data showed a warming of the water column after the year 1990, particularly relevant in the cold season. Surface salinity increased in spring and summer and strongly decreased in autumn and also in winter (due to the spreading over the basin of the increased autumnal river runoff). These changes, combined with anthropogenic effects, appear to influence the northern Adriatic marine environment and ecosystems. Impacts in the coastal areas are also evident inland; the analysis of Aridity index, and potential water deficit, suggests negative impacts in terms of soil deterioration and agricultural productivity, particularly in the area near the coastline. At the same time, the analysis of social data revealed awareness among local residents of these impacts and associated risks connected to climate change. Yet, this awareness is not currently translated into preventive and protective actions; among the main reasons for this delay is also ineffective information exchange among citizens, public administrators, and the scientific community.

Keywords Regional climate · Adriatic Sea · Marche · Climate change perception

F. Appiotti · A. Russo (✉) · F. Marincioni
Department of Life and Environmental Sciences,
Università Politecnica delle Marche, Via Brecce Bianche,
60131 Ancona, Italy
e-mail: a.russo@univpm.it

Present Address:
F. Appiotti
Department of Design and Planning in Complex Environment,
IAUV, Venezia S. Croce 1957, 30135 Venice, Italy

M. Krželj
Department of Marine Studies, University of Split,
Livanjska 5/III, 21000 Split, Croatia

A. Russo
ISMAR, CNR, Via Gobetti, 101, 40129 Bologna, Italy

M. Ferretti
Department of Integrated Policies for Security and Civil
Protection, Regional Council of Marche, Via Gentile
da Fabriano 3, 60125 Ancona, Italy

M. Bastianini
ISMAR, CNR, Arsenale - Tesa 104, Castello 2737/F,
30122 Venice, Italy

Introduction

The Earth's climate is changing, with unequivocal increases of global average air and ocean temperatures. Despite the fact that climatic variations are a normal expression of the dynamic nature of planet Earth, the current speed of these changes does not seem to find precedents in the planet's recent climate record (IPCC 2007). During the twentieth century, the climatic patterns have produced significant alterations of the hydrogeological cycle on Earth's surface and increased the intensity and frequency of extreme weather events related to it. These accelerated changes have cascade effects with many linkages at global level and variegated local impacts. For this reason, it is essential to develop climate investigation analysis taking into consideration both global and local levels. Differently from global analysis, local climate analysis can more accurately represent the complex climate of a small area and offer new insights into precipitations and temperature patterns (Boyles and Raman 2003), and to the specific area-related effects. As a matter of fact, the amount and type of consequences related to the ongoing climate change are closely dependent on individual ecosystems and differ strongly on spatial scale, in relation to the geographical setting of the area considered, and its socioeconomic condition. In order to define useful and effective strategies to reduce the risks emerging from climate change and to help local communities to adapt to future scenarios, it is very important to understand, not only how climate parameters are changing, but also how people and decision-makers perceive these changes.

This study takes into consideration different aspects of the climate change analysis in the Italian coastal region of Marche and in the northern part of the Adriatic Sea. In particular, the study tries to coherently integrate both physical and social data; to define rational and adaptive local strategies.

Temperature and precipitations trends over the Italian peninsula during the last century have been investigated by several studies (Cundari and Colombo 1992; Maugeri and Nanni 1998; Buffoni et al. 1999; Brunetti et al. 2000a, b, 2004, 2006; Colombo et al. 2007; Toreti and Desiato 2008). These studies demonstrated an increasing maximum and minimum temperature trend since 1980 with small differences from North to South, and a significant reduction of annual and seasonal precipitations. During the twentieth century, precipitation has decreased by about 5 % in the Northern Italy and by about 15 % in the South (Buffoni et al. 1999). Moreover, Brunetti et al. (2006) reveals that the area with the most marked annual precipitation decreasing trend is the central-southern Italy with a reduction of 10 % in the last century. Furthermore, winter is the season characterized by a stronger precipitation reduction over the whole of Italy and especially in its Northern part (Brunetti et al. 2000a).

The variations in climate trends are also affecting soil compartment. Due to its localization and its geomorphologic characteristics, the Italian peninsula is strongly exposed to drought and desertification hazards. Although actually not yet significantly involved by these hazards, the Marche region appears, especially in the coastal band, to be one of the Italian areas potentially at risk of drought and desertification impacts (Costantini et al. 2007). Actually, the risk of desertification is expected to be the highest in areas with projected decreases in precipitation, increases in the frequency of summer droughts and the incidence of forest fires, and intensive land use (EEA/JRC/WHO 2008).

Climate is one of the most important agents in the process of desertification and soil degradation. A fitful climate appears to be the main cause of erosion, landslides, and flooding (Costantini et al. 2007; EE/JRC/WHO 2008). Moreover, the climate can build the limiting factor for plant growth because of low rainfall and high temperatures, making unprofitable agricultural cultivation in the absence of irrigation (Costantini et al. 2007). The temperature acts on the soil either directly or indirectly (evapotranspiration) contributing to the process of salinization, aridification, and degradation of organic matter. Indeed, possible future effects of climate change on soil productivity and desertification are strictly dependent on both climatic and agro-meteorological parameters (e.g., temperature, precipitation, potential water deficit and Aridity index), and soil moisture characteristics (ASSAM 2006). The Aridity index and the potential water deficit are indicators that can be calculated by collecting and processing meteorological data, such as air temperature, precipitation, and evapotranspiration (Nastos et al. 2011).

Coastal areas are among the most threatened by climate change, because of sea level rise and potential modifications of the environmental parameters in the shelf areas. This aspect is particularly relevant, considering that an important portion of the human population lives in coastal areas. Coastal erosion, changes of river discharge, modifications of sea temperature, salinity, circulation and nutrient salts content, eutrophication, anoxia, and alien species are some of the factors which may affect the coastal and marine environments.

Finally, climate change is a complex phenomenon which involves diversified aspects of life and push citizens and institutions to define effective strategies to face with new future conditions and emerging risks. People's predisposition to implement mitigation and adaptation strategies, as well as to support and urge governments to do the same, is not directly related to the real level of risks but to the perceived one (O'Connor et al. 1999). Threats and hazards interact with psychological, social, institutional, and cultural processes in ways that may amplify or attenuate the public perception of risk. The channels of this amplification or attenuation process are strongly related to the information transfer mechanisms (direct and indirect communication), personal knowledge of cause and consequences of climate change, past experiences, and cultural and environmental beliefs (Kasperson et al. 1988). All these aspects, acting on public and personal perception of risk, may increase people's willingness to take action to reduce risk and to adapt to new conditions.

The interaction and exchange of information among experts of disaster prevention, politicians, and citizens play an important role in disseminating disaster knowledge and shaping individual and collective risk conscience (Gray et al. 1999).

This manuscript confronts the scientific evidence of climate change, on different environmental domains, with local residents, policy makers, and emergency managers' perception of the emerging climate risks. After introducing the environmental context, the following section describes the study area. Research methodology and data collection are reported in the third section, whereas trends and changes analyzed in the air, water, soil, and humans realms are discussed in the fourth one. The last section presents the results and the discussions about prevention strategies of future impacts.

Study area

The study area considered in this work includes the Marche region in central Italy and the northern part of the Adriatic Sea (Fig. 1).

The Marche region

This is one of the 20 administrative division of Italy, it is located around latitude 43°N and longitude 14°E, extends for a total surface of 9.385 km^2 and counts 1,565,000 residents. The regional climate is affected by the presence of the Adriatic Sea to the east and of the Apennines mountains chain to the west. The coastal area that extends north to south for 173 km is the most productive zone of the region. From east to west, the region can be subdivided in three different thermal and geomorphological bands: coastal, valley/low hill, and high hill/mountain. Some 69 % of the territory is valley and low hill, prevalently composed of clayey sandstone sediments, and 31 % is high hill and mountain with a large part composed of massive limestone. Only a small portion presents coastal morphology along the Adriatic seaboard. Finally, about 30 % of the territory is covered by forests.

From a climatic perspective, each of these bands shows different temperature and precipitation trends, with the mean annual temperature of 15, 14 and 13 °C, respectively (Murri and Fusari 1987). July and August are the months with highest temperatures, while the lowest ones are generally recorded in January. In terms of precipitation, the *coastal band* receives mean precipitation values ranging from 600 to 850 mm/year, the *medium–low hill band* between 850 to 1,000 mm/year, and the *high hill and mountain band* over

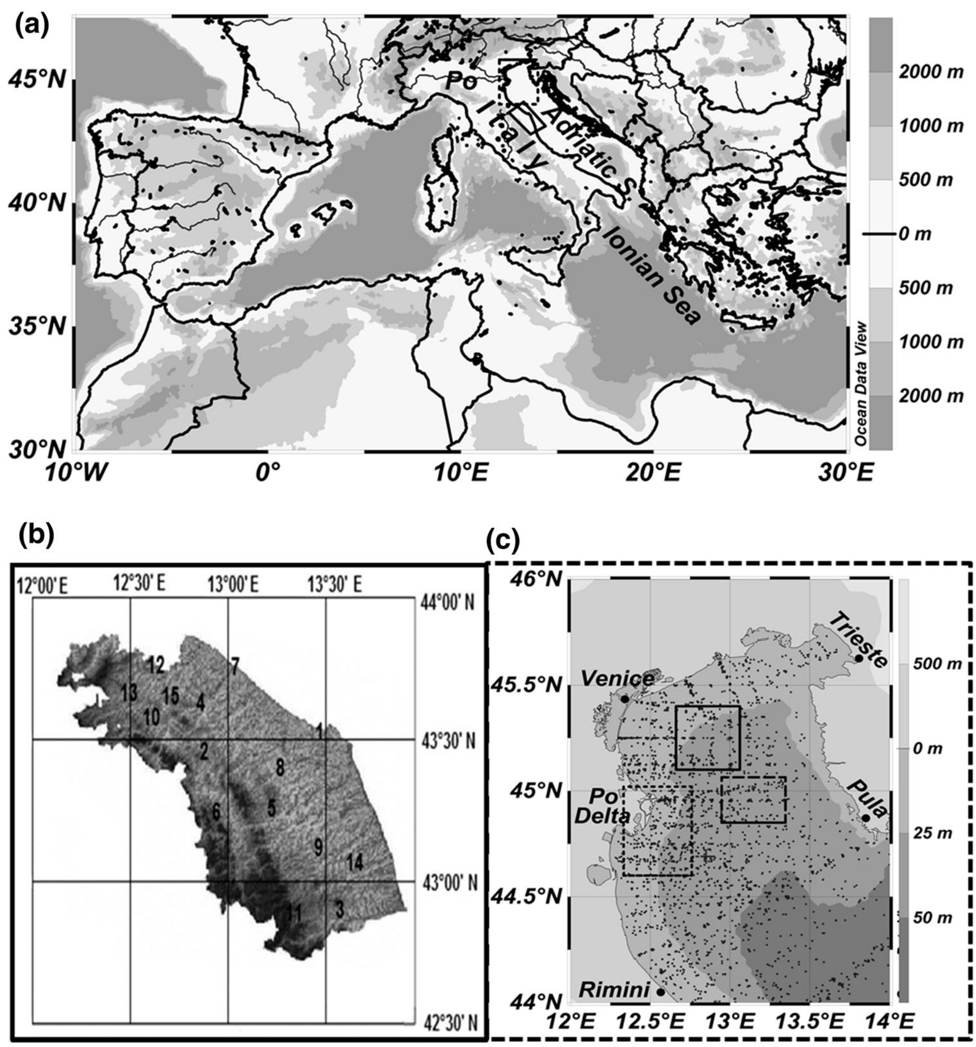

Fig. 1 Study area: **a** The Mediterranean basin, with the *box* indicating Marche region and the *dashed box* the investigated northern Adriatic area; **b** the Marche region with the numbers corresponding to the location of temperature stations as reported in Table 1; **c** position of the oceanographic stations within the marine study area. Location of 4 meteo stations is reported; the three boxes represent marine areas considered for time series in the northern Adriatic Sea: *Po* dotted, *Nord* continuous, *Est* dashed

1,000 mm/year. Autumn is the rainy season, with the exception of the third band (high hill and mountains) where the rainy season is winter (Grassi and Zepponi 2009).

In terms of soil aridity, 15.5 % of regional coastal and low valley areas are currently considered at risk of desertification (Grassi and Zepponi 2009). Considering that in 2002 the Marche region was defined an area not vulnerable to desertification (Grassi and Zepponi 2009), the sizeable increase over the last 10 years of the area at risk of desertification is likely due to the great climate variability that is affecting the Mediterranean basin.

The northern Adriatic Sea

This is a shallow shelf basin with a maximum depth of about 100 m and is located at the northernmost tip of the Mediterranean Sea. It has a limited and confined area and volume but receives large river runoff capable of influencing the deep circulation of the adjacent Ionian Seas, and the whole of the Eastern Mediterranean Sea. The northern Adriatic is also an important economic resource area hosting huge maritime traffic, fisheries, aquaculture, and offshore activities (drilling plants for mainly natural gas extraction, and presently also Liquefied Natural Gas—LNG, regasification terminal) as well as tourism. Unquestionably, coastal erosion, massive mucilaginous aggregates, harmful algal blooms, biogeochemical fluxes, modifications due to climate change heavily affect tourism and fishery, two most relevant economic activities of the Marche region.

Due to its shallowness and topography conditions (as surrounded by land and mountainous chains, such as the Apennines to the West, the Alps to the North, and the Dinaric Alps to the east), the northern Adriatic Sea responds faster and more intensely to changes in the boundary conditions (atmosphere and river runoff *in primis*). The Po River, which flows into the Adriatic about 100 km northwestward of the coastline of Marche, with its 1,500 $m^3 s^{-1}$ long-term average runoff is one of the major driver of the Adriatic environmental dynamics. The Adriatic sea's general circulation is cyclonic moving freshwater input from the Po, and the other northern Adriatic rivers, southeastward along its western coast, directly influencing the Marche coastal area (Artegiani et al. 1997). In fact, the rivers of Marche have an annual average runoff on the order of tenths of cubic meters per second and are unable to heavily influence surface seawater salinity (and other properties), except for the first few hundred meters around the rivers' mouth. The Po River is also the largest nutrient point source in the northern Adriatic, and its freshwater spreads significantly influence the water column stratification and the circulation pattern, contributing to large spatial and temporal variability of eutrophication gradient and primary production in that area (Smodlaka 1986; Degobbis and Gilmartin 1990; Gilmartin et al. 1990; Raicich 1996; Degobbis et al. 2000; Tedesco et al. 2007a, b; Socal et al. 2008; Cozzi and Giani 2011; Djakovac et al. 2012; Giani et al. 2012).

Materials and methods

To define the general climatic trends in the Marche region, daily temperature and precipitation data were collected and analyzed for the 50-year period 1960–2009. The dataset was obtained from the Marche Region's "Centro Funzionale della Protezione Civile" (the regional monitoring and forecasting center for civil protection). This center is responsible to collect and manage the regional meteorological data since 2002. Before that, all the data were collected from the "Italian National Hydrographic and Maritime Office." The data for this study were gathered from 21 temperature and 61 precipitation stations distributed over the territory of Marche. Yet, due to the presence of missing values, not all the records available from these stations have been used for the statistical analysis performed for this work. According to the recommendations of the "Guide to Climatological Data" (WMO 2007), the monthly values of temperature were not calculated if: (1) 10 or more daily measures were missing or (2) 5 or more consecutive daily measures were missing. Applying such criteria data from only 14 stations of minimum temperature (T_{min}) and 15 stations for maximum temperature (T_{max}) were analyzed (Fig. 1b; Table 1). Conversely, the precipitation data were selected on the base of general criteria used by the European climate assessment and dataset (ECAD), which establishes that (a) data must be available for at least 40 years, (b) the total missing data cannot be more than 10 %, (c) the missing data from each year cannot exceed 20 %, and (d) the period of missing measures cannot exceed 3 consecutive months (Bartholy and Pongracz 2007).

From these daily data, annual trends for maximum and minimum temperature (T_{max} and T_{min}), and precipitation over Marche were also analyzed over the period 1960–2009. Furthermore, seasonal trend for each station was calculated according to the following seasonal breakdown:

Winter: January, February, and March,
Spring: April, May, and June,
Summer: July, August, and September,
Autumn: October, November, and *December*.

These are not the astronomical time periods used for these seasons (there is a delay of about 10 days); yet, such averaging strategy avoids having few December's data falling in the previous year. Also, oceanographic data analysis uses the above seasonal breakdown.

Table 1 Results of the Mann–Kendall statistical test applied to the seasonal values of the maximum/minimum air temperature at selected stations

Time series	Winter				Spring			
	T_{max}		T_{min}		T_{max}		T_{min}	
	Test Z	Sign	Test Z	Sign	Test Z	Sign	Test Z	Sign
Ancona	3.3	***	4.9	***	4.3	***	4.9	***
Arcevia	2.3	*	4.5	***	3.2	**	3.7	***
AscoliPiceno	2.3	*	1.8	+	2.7	**	3.7	***
Bargni	3	**	3.6	***	3.1	**	3.4	***
Cingoli	0.8	ns	5.1	***	2.1	*	4.5	***
Fabriano	0.8	ns	0.3		2.7	**	2	+
Fano	3.4	***	5.7	***	4.3	***	5.1	***
Jesi	1	ns	2.4	*	0.2	ns	3.2	**
Lornano	2.7	**	3.4	***	3.8	***	3.6	***
Mercatello	2.3	*	4.1	***	2.2	*	3.8	***
Montemonaco	2.9	**	3	**	2.6	*	1.6	ns
Novafeltria	1.5	ns	3.7	***	2.8	**	3	**
Pergola	2.8	**	0.7	ns	1.7	+	0.9	ns
Servigliano	3.8	***	−4.2	°°°	5.4	***	−2	°
Urbino	1.2	ns	4.2	***	3	**	3.5	***
Time series	**Summer**				**Autumn**			
	T_{max}		T_{min}		T_{max}		T_{min}	
	Test Z	Sign	Test Z	Sign	Test Z	Sign	Test Z	Sign
Ancona	4.7	***	4.2	***	3	**	2.7	**
Arcevia	4	***	4.2	***	3.1	**	2.9	**
AscoliPiceno	3.5	***	3.1	**	1.3	ns	1.5	ns
Bargni	2.8	**	2.9	**	1.9	+	2.3	*
Cingoli	1.5	ns	4	***	−0.4	ns	3.8	***
Fabriano	2.2	*	2	*	−1.1	ns	0.3	ns
Fano	5.5	***	5.5	***	4.3	***	4.8	***
Jesi	−0.2	ns	2.8	**	0.5	ns	2.1	*
Lornano	4.3	***	3.9	***	1.2	ns	2.1	*
Mercatello	2	*	4.4	***	1.1	ns	2	*
Montemonaco	2.8	**	1.6	ns	2.8	**	1.7	+
Novafeltria	1.2	ns	3.2	**	1.2	ns	2.4	*
Pergola	1.5	ns	1.1	ns	0.4	ns	0.6	ns
Servigliano	5.8	***	−0.6	ns	4.3	***	−2.5	°
Urbino	3.6	***	3.7	***	−0.2	ns	3.1	**

Positive trend: ns not significant, $^{+}$ $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Negative trend: ns not significant, $V = P < 0.1$, ° $P < 0.05$, °° $P < 0.01$, °°° $P < 0.001$

The time series of rainfall and temperature were analyzed using the Mann–Kendall (MK) statistical test (Mann 1945; Kendall 1975). This is a rank-based nonparametric test (Novotny and Stefan 2007), commonly used to assess the significance of the hydro-meteorological time series trends of temperature, precipitation, and streamflow (Westmacott and Burn 1997; Yue et al. 2002).

The Mann–Kendall test was carried out using Makesens (Mann–Kendall test for trend and Sen's slope estimates) and template (Salmi et al. 2002). Four different significance levels α where chosen for this study: 0.1, 0.05, 0.01, and 0.001 to which correspond the levels of confidence of 90, 95, 99, and 99.9 %, respectively. The Z was instead used to identify a statistically significant trend and direction (Table 1). Positive (negative) values of Z indicate an upward (downward) trend (Salmi et al. 2002). The results obtained from temperature and precipitation trend analyses are illustrated in the GIS maps. In addition, annual and seasonal percentage precipitations were compared with the climatological normal "CliNo" 1971–2000, in order to show local anomalies. Using GIS, the anomalies for five different time periods: (a) 1961–1970; (b) 1971–1980; (c) 1981–1990; (d) 1991–2000; (e) 2000–2009 were spatially interpolated through the inverse distance weighted (IDW) method. IDW infers that each station has a local influence that decreases with distance (Cannarozzo et al. 2006). The use of GIS has enabled the production of maps and the identification of areas that are changing differently from others.

Marine data were extracted from the datasets of MEDAR/MEDATLAS 2002 (MEDAR Group 2002) and of the Institute of Marine Science–National Research Council (ISMAR-CNR). Oceanographic stations were mainly available from 1970 up to 2007 and were gathered from over 8,000 stations recording temperature and salinity data; about half of these stations also measured nutrient salts and chlorophyll values. Two main temporal periods were compared: (1) 1970–1999 and (2) 1990–2007. Horizontal climatological distribution across the northern Adriatic domain, shown in Fig. 1c, was generated by means of an Objective Analysis procedure. This was performed for the two time periods, over the four seasons at three different depths: (1) surface (up to 3 m depth), (2) intermediate (20 m), and (3) bottom (within 5 m from the sea bottom) which in the study area was never deeper than 50 m. Anomalies were highlighted by subtracting the first period climatologies (1970–1999) from the recent period (1990–2007) climatologies. Full details can be found in Krželj (2010) and Russo et al. (2002). These works also describe the Po River flow data at Pontelagoscuro (the last gauge station before the Po delta ramification) using data collected by the Po River Basin Authority (Parma, Italy) and the Hydro-Meteo-Clima Service of the Emilia Romagna Region's Environmental Protection Agency (Bologna, Italy). Daily discharges data from 2005 to 2010 of some of the main rivers (Metauro, Misa, Potenza, and Tronto) monitored in Marche were also provided by "Centro Funzionale della Protezione Civile".

Another part of the study took into consideration the analysis of two agro-meteorological parameters: Aridity index (I_a), and potential water deficit ($PSMD_{max}$). In order to calculate these indices, only stations that recorded both precipitation and temperature data were selected. The Aridity index "Ia" is a numerical indicator of the degree of dryness of the climate at a given location (Nastos et al. 2011). For this study, it was employed the UNEP (1992) formula:

$$I_a = P/ET_P$$

where "P" is the average annual precipitation (mm) and "ET_P" is the average annual evapotranspiration (mm). The Aridity index was analyzed separately for each station through the construction of graphs showing the trend for all the available time series. Furthermore, using Makesens software (Salmi et al. 2002), the nonparametric Mann–Kendall statistic test (Westmacott and Burn 1997) was calculated in order to examine the nonlinear trend at each station.

The potential water deficit "$PSMD_{max}$" is the theoretical deficit that can be measured in a field completely covered with grass, with optimal water conditions and without restrictions of evapotranspiration (Green 1963). The deficit represents the summation of the differences between the monthly precipitation and the reference evapotranspiration (Duce et al. 2003):

$$PSMD_{max} = \sum (P - ET_0)$$

where "P" is the average annual precipitation (mm) and "ET_0" is the daily potential evapotranspiration (mm) calculated for each station (over the 50 years study period) applying the method of Thornthwaite (1948). The potential water deficit index was analyzed considering two subperiods 1960–1990 and 1970–2000, and the mean values of the index, for each available station, were calculated and spatially analyzed using GIS and an IDW method of interpolation.

Finally, the socio-anthropological data necessary to assess the perception of climate change risks in the Marche region were collected administering questionnaires to: (a) local residents, (b) local policy makers, and (c) municipal emergency managers. The questionnaires were distributed during the months of February, March, April, and May 2010 using a purposive spatial sampling method (Stallings 2002). The data collected through 800 questionnaires were analyzed and interpreted using qualitative and quantitative methods. When applicable, statistical analyses were carried out using the SPSS 13.0 software (SPSS 2003).

Results

Air temperature

Detection and prediction of long-term changes in temperature patterns are often the driving force in climate change analysis (Boyles and Raman 2003). Temperature variations in Marche follow specific monthly and seasonal patterns. The statistical analysis revealed that 78, 5 % of the temperature stations detailed a positive and significant trend in

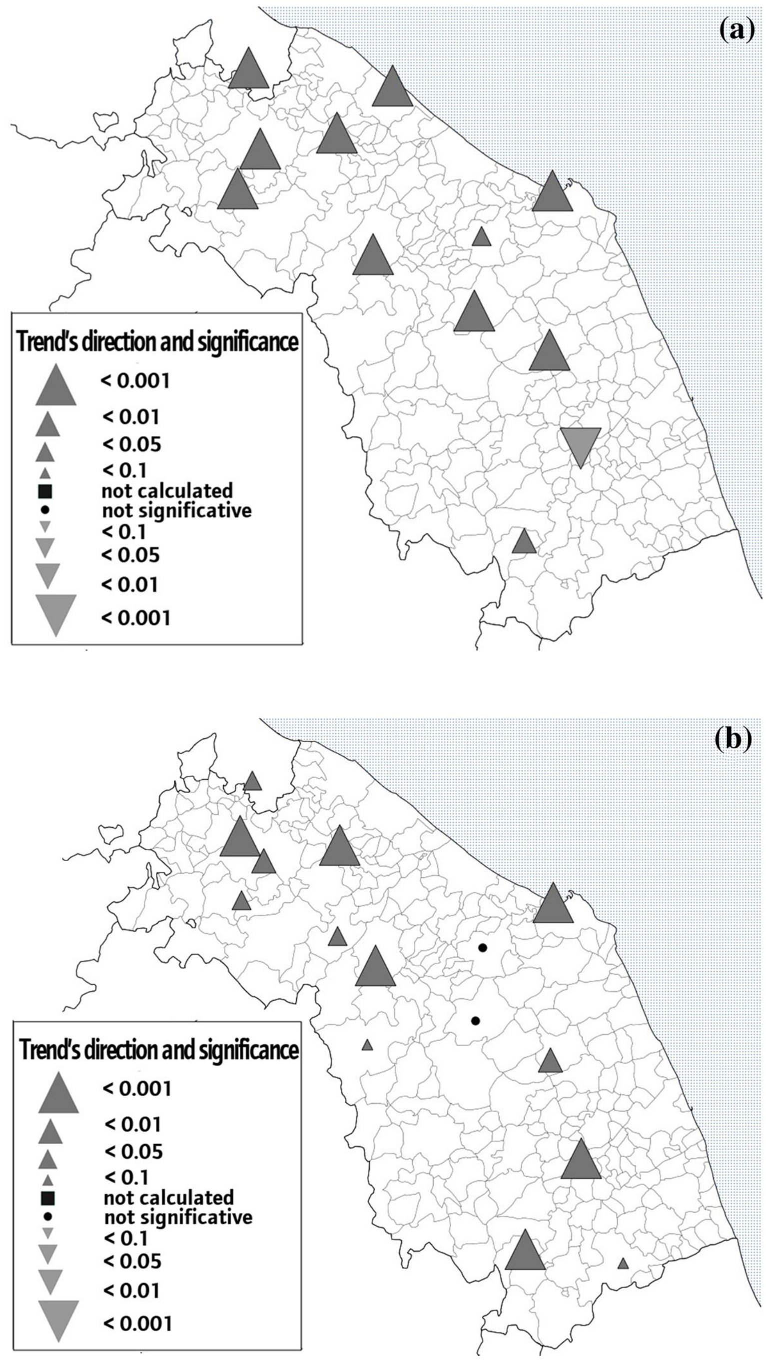

Fig. 2 Tendency of annual minimum temperature $T_{\min}$ (**a**) and maximum temperature Tmax (**b**) over the period 1960–2009 calculated using the Mann–Kendall statistical test. Annual temperature trends are shown at four levels of confidence: 90, 95, 99, and 99.9 %. The *triangles* size correspond to the trend's level of confidence, whereas the *upper* or *lower vertex* indicates increasing or decreasing changes; stations indicated by *black dots* did not show statistically significant variation

annual minimum temperature ($T_{\min}$) of, in average, 0.33 °C per decade. Moreover, the positive trend is mainly located in the northern and central parts of the region (Fig 2a). At the same time, the Mann–Kendall test, conducted on annual maximum temperature, shows that 87 % of the stations detailed a significant increase in annual temperature (Fig 2b) of, in average, 0.43 °C per decade. Similar results are found at seasonal level (Table 1) where it is possible to notice a significant increasing trend that interests both $T_{\min}$ and $T_{\max}$ in all seasons. The seasons interested by a more significant increasing trend are spring and summer minimum temperature. Significant stations of seasonal analysis on decadal basis show average increases 0.27 °C greater than the reported annual one for summer $T_{\max}$ and about 0.13 °C for winter and spring $T_{\max}$; 0.07 °C greater than the reported annual one for spring and summer $T_{\min}$. Temperature increases for remaining seasons are minor

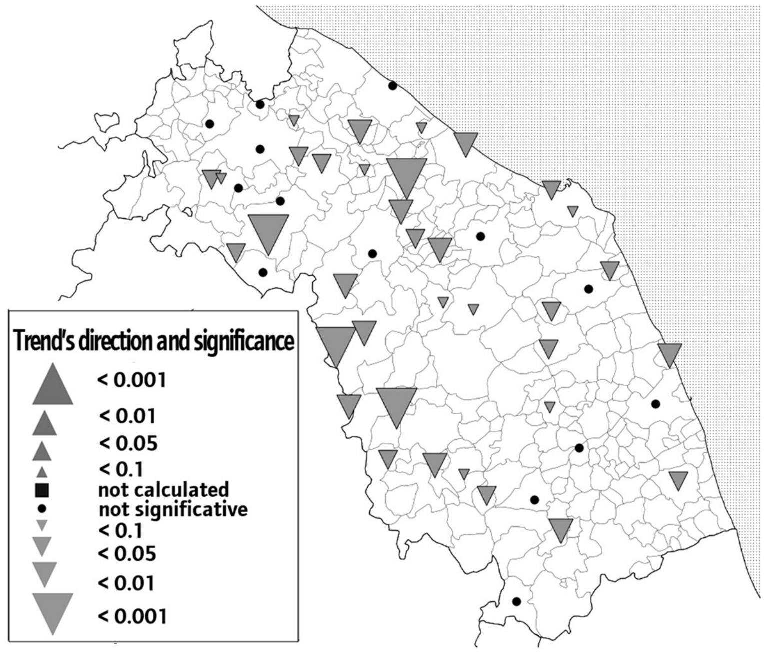

Fig. 3 Tendency of annual precipitation over the period 1960–2009. Annual precipitation trends are shown at four level of confidence: 90, 95, 99, and 99.9 %. The *triangles* size correspond to the trend's level of confidence, whereas the *upper* or *lower vertex* indicates increasing or decreasing changes; stations indicated by *black dots* did not show statistically significant variation

than the annual ones: 0.03 °C less for autumn T_{max}; about 0.07 °C less for winter and autumn T_{min}.

Precipitations

Precipitation is a particular and unique climatic variable, primarily because it is not a continuous one. Precipitations in Marche are often spotty with specific patterns of distribution and seasonal behaviors (Murri and Fusari 1987; Grassi and Zepponi 2009). July is the least rainy month, while October, November and December are the rainiest. Daily precipitation data from 61 recording stations in the Marche region were obtained from the Marche Civil Protection's database. Yet, due to the high number of missing data for some of these stations, it was possible to use data only from 51 stations. The daily records were summed to obtain seasonal and annual totals for each year. Afterward, seasonal and annual time series were statistically analyzed with the Mann–Kendall test. The results reveal a significant trend of annual precipitation in 35 of such stations. The relative values of the statistical analysis are all negative indicating a widespread decreasing tendency in annual rainfall (Fig 3).

Statistical tests were also conducted using seasonal data. The analysis of winter data highlights that most stations (32 of 51) detailed a significant decreasing rainfall trend, especially along the coast and in the central regional band (Fig 4a). This is the strongest trend of rainfall decrease of all seasons; in fact, spring and summer data revealed a significant rainfall decreasing trend for 12 and 9 stations, respectively (Fig 4b, c), while in autumn, no significant trend is detected in any station (Fig 4d). Thus, it appears that the winter negative trend is the main driver of the negative annual trend.

After the statistical determination of annual and seasonal precipitation trends, the entire time series was divided into 5 decades. For each one of the analyzed stations, the percentage anomaly, with respect to the CliNo 1971–2000, was calculated within each decade. As suggested by the Guide to climatological practices of WMO (2007), the climatological normal 1971–2000 was used. Using GIS, the percentage anomalies from each station and each decade were spatially analyzed for different seasons. Results showed that winter is characterized by an overall negative trend, while autumn show not significant overall trend. The maps created with winter data (Fig 5a–e) highlight a substantial precipitation decrease up to the fourth decade (1990–1999). Comparing this period with the CliNo reference, the percentage anomalies reach negative values ranging from 5 to 20 % and in some areas even beyond 50 %. The greatest rainfall reductions are concentrated in the northern part of the region. During the first decade, almost everywhere, the precipitation values are higher than CliNo from 5 to 40 %. The last decade shows a diffuse decrease in the winter rainfall with values of 10 % primarily in the coastal areas and in the south–west part (mountain area), while the remaining sectors show a certain precipitation recovery.

The above results appear related to the North Atlantic Oscillation (NAO) index, which influences the autumn and winter precipitation pattern (mainly the December–March interval) in the Mediterranean basin (Hurrell 1995). During

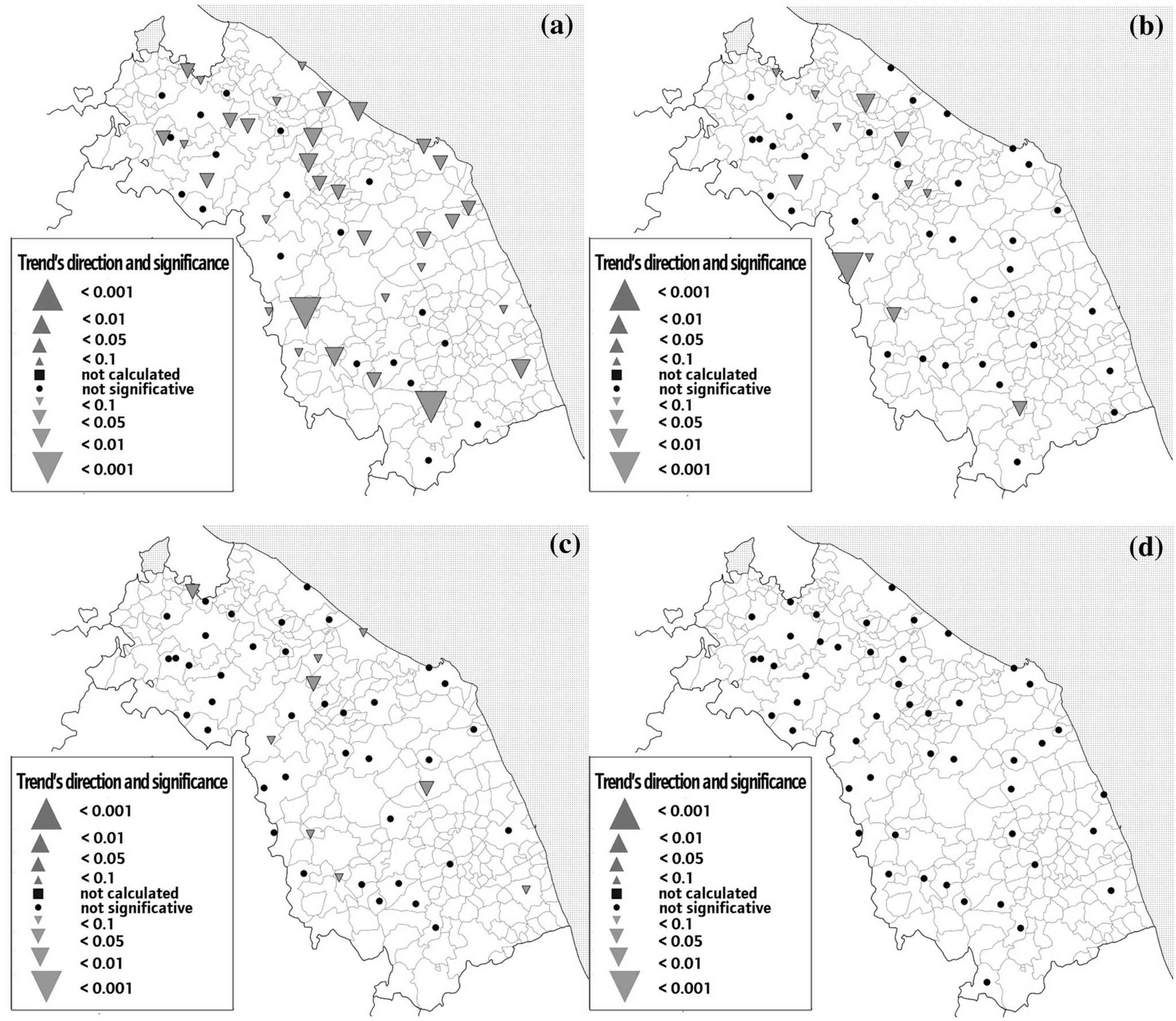

Fig. 4 Precipitation trends for Winter (**a**); Spring (**b**); Summer (**c**); Autumn (**d**). Precipitation trends are shown at four level of confidence: 90, 95, 99, and 99.9 %. The *triangles size* correspond to the trend's level of confidence, whereas the *upper* or *lower vertex* indicates increasing or decreasing changes; stations indicated by *black dots* did not show statistically significant variation

our period of investigation, the NAO index was in positive phase, growing during the 1990–1999 decade and slightly decreasing in the last decade. Autumn precipitations show alternating anomalies (Fig 6a–e) that highlight some differences with respect to the other seasons. The decades 1960–1969 and 1990–1999 are characterized by positive rainfall anomalies at most of the stations. The decade 1970–1979 is characterized by prevalent negative anomalies. On the contrary, the 1980–1989 decade and even more the last decade (1990–1999) show different parts of the region with a different behavior. The last decade is characterized by an increase in precipitation in the mountain band, while in the northern coastal band, a variable decrease of seasonal rainfall range from 0 to 5 %, and 10 to 15 %.

Finally, seasonal precipitation average was compared over the periods 1970–1989 and 1990–2007 (as it was done with the marine and Po River discharge data). Results show a general reduction in spring, summer, and especially in winter, while autumn displays a general increase (Fig 7a).

Marine data and river flow

Comparing sea temperatures (Fig. 7b) over the period 1970–1989 with those over the recent period 1990–2007, a

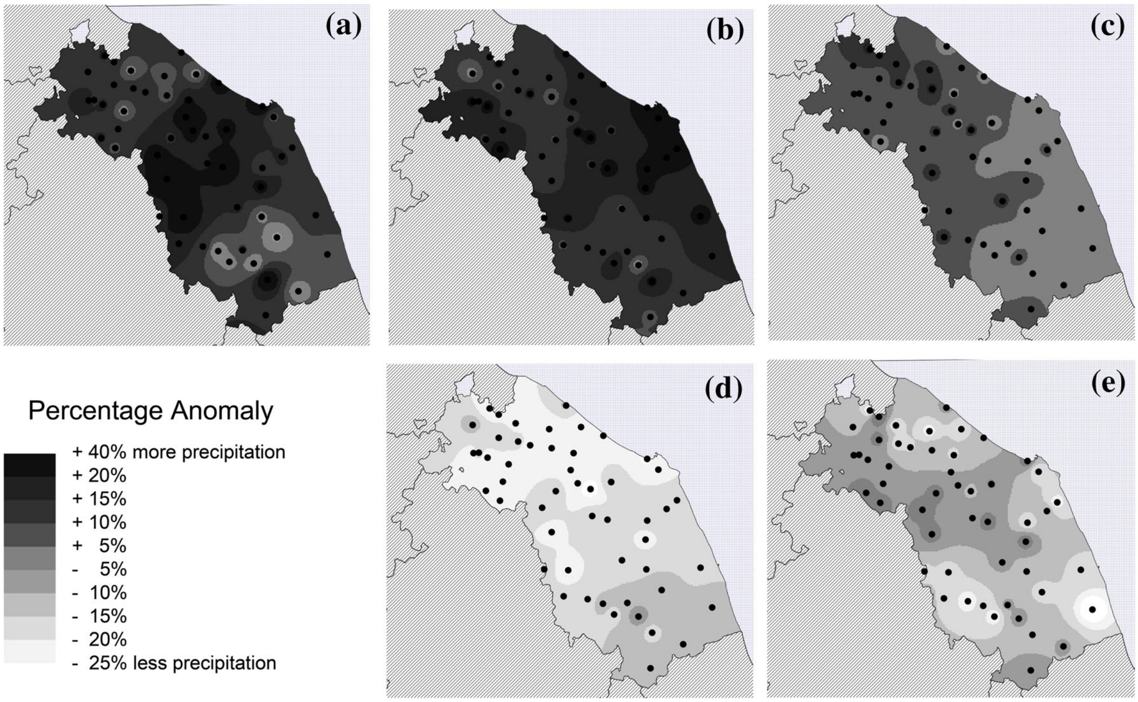

Fig. 5 Percentage anomaly of winter precipitation compared to the climatological normal 1971–2000 for five different decades: 1960–1969 (**a**); 1970–1979 (**b**); 1980–1989 (**c**); 1990–1999 (**d**); 2000–2009 (**e**). Areas with negative/positive anomalies are indicated by the *greyscale*. Considered stations are indicated by *black dots*

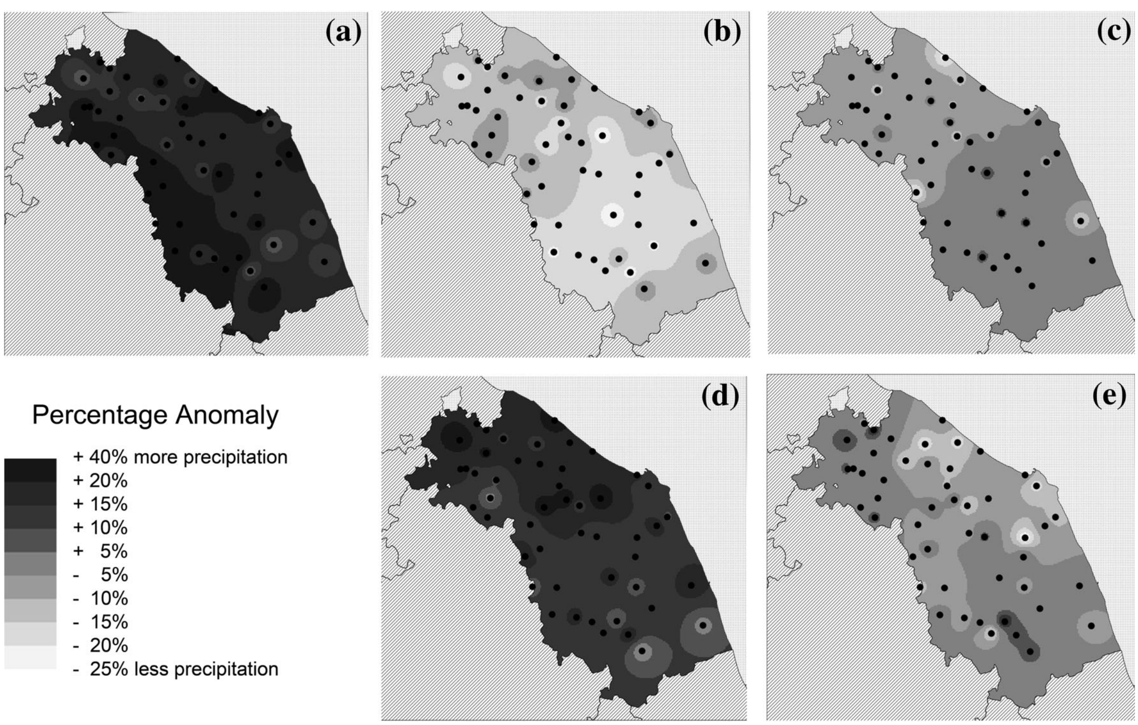

Fig. 6 Percentage anomaly of Autumn precipitation compared to the climatological normal 1971–2000 for 5 different decades: 1960–1969 (**a**); 1970–1979 (**b**); 1980–1989 (**c**); 1990–1999 (**d**); 2000–2009 (**e**). Areas with negative/positive anomalies are indicated by the *greyscale*. Considered stations are indicated by *black dots*

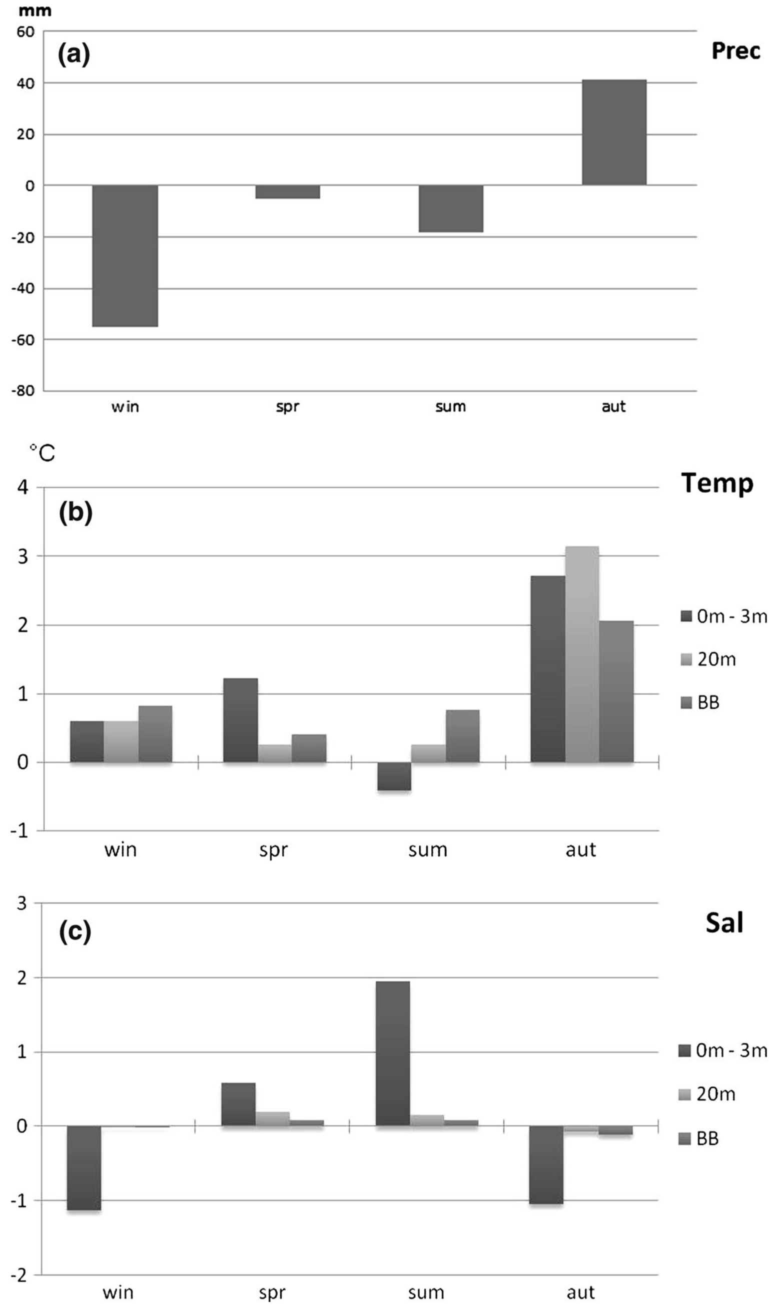

Fig. 7 Spatial average seasonal anomaly of precipitation on Marche (**a**), sea temperature (**b**), and salinity (**c**) of the northern Adriatic Sea for the 1990–2007 period versus the 1970–1989; marine data were computed at three layers (surface, 20 m and *bottom*)

general increase at all depths and seasons (except at sea surface in summer) is observed. This warming is particularly relevant in autumn (between 2 and 3 °C). The sea surface temperature slight decrease in summer should be due to a decreasing trend of summer air–sea heat fluxes detected in the northern Adriatic Sea during the investigated period (Supić, personal communication). Surface salinities (Fig. 7c) show an increase in spring and particularly in summer, while autumn and winter have a large decrease. Looking at deeper layers, salinity values show similar variations (increase in spring and summer, decrease in autumn), even though less pronounced than those in the surface. Considering that the investigated northern Adriatic area receives freshwater mainly from the Po River, the large sea surface salinity variations are likely due to changes in the Po River discharge. Data show that the Po river's discharge decreased in winter, spring, and summer, up to about 25 % during spring (Fig. 8a, b, c), and increase of about 25 % during autumn (Fig. 8d). Autumn and spring are the seasons of maximum discharge for the Po River, the first caused by large autumn precipitation and the second by spring snow melting (mainly on Alps). Trend analysis reveals that over the recent period (1990–2007), all seasons registered decreasing Po River discharges, except for autumn.

The investigated marine area is not directly bordering on the Marche coastline; yet, the detected changes are also

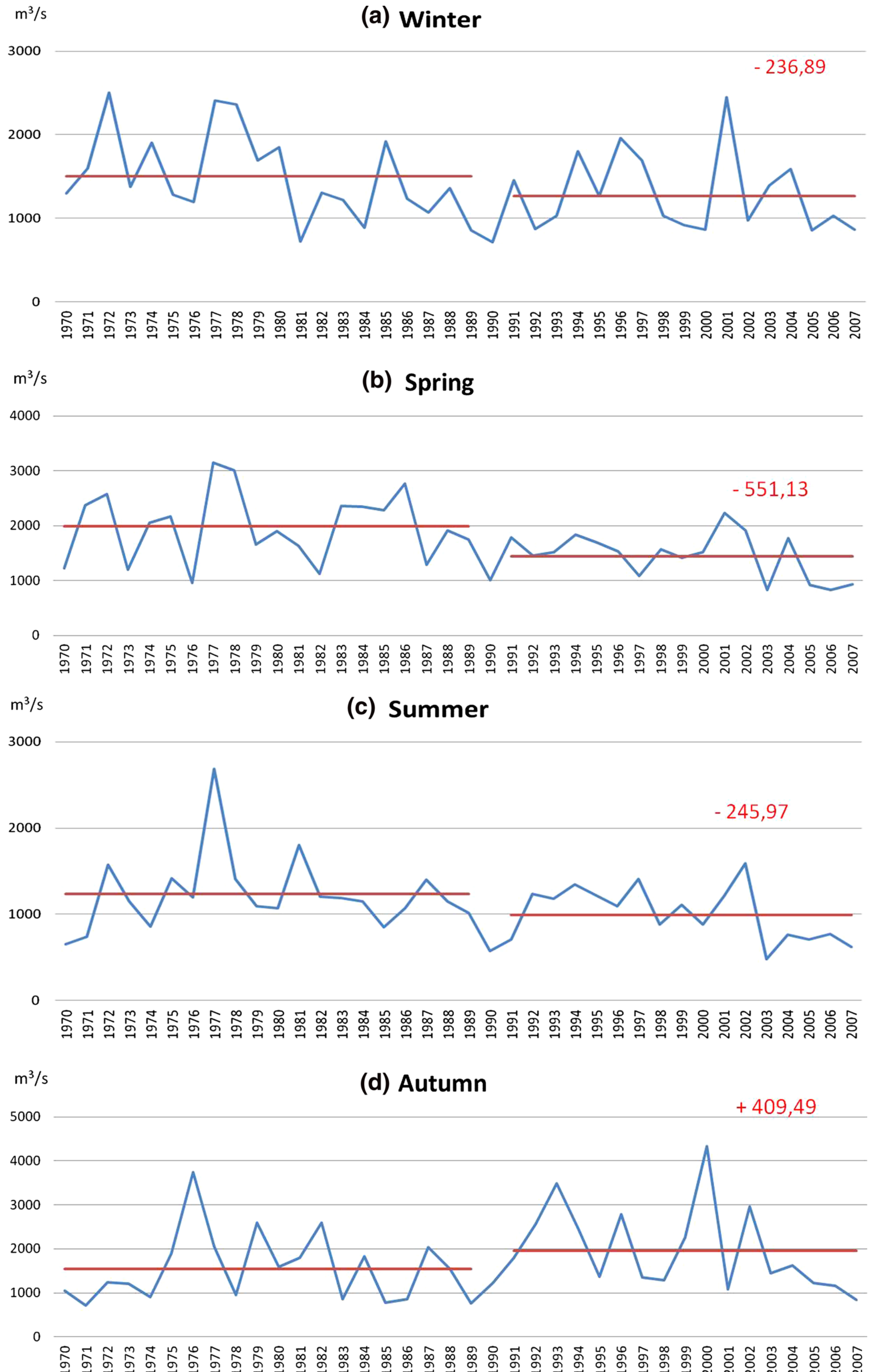

Fig. 8 Time series of Po River seasonal mean discharge ($m^3\ s^{-1}$) at Pontelagoscuro for Winter (**a**), Spring (**b**), Summer (**c**), and Autumn (**d**)

experienced in the Marche seawaters. As said above, the cyclonic (anticlockwise) general circulation of the Adriatic Sea advects relevant signals toward southeast (Artegiani et al. 1997). The rivers of Marche have limited drainage basins (almost completely in the Marche region, Fig. 9), and continuous time series over the investigated period are not available. From 2005 to 2010, the main four monitored rivers (Metauro, Misa, Potenza and Tronto) have an

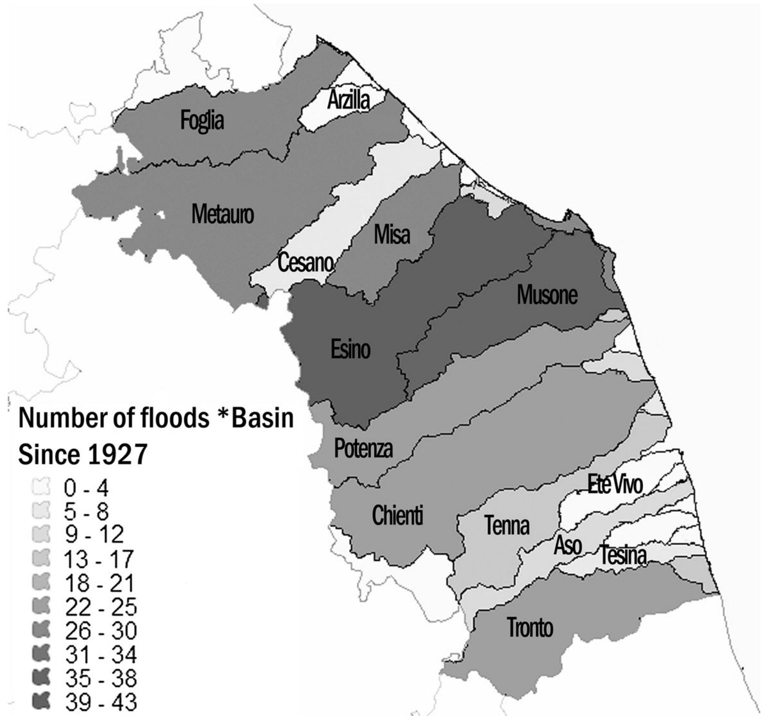

Fig. 9 Marche drainage basins; *greyscale* represents the number of floods reported from 1927 to 2009 in each basin

average yearly discharge ranging between 1 and 20 $m^3 s^{-1}$. Figure 9 reports also the flood events documented in the region from 1927 to 2009 (Hydro-Meterological Annals and Italian National Research Council IRPI online database http://sici.irpi.cnr.it/). It appears that the drainage basins in the central and northern part of the region flood more frequently than those located in the southern part. Notwithstanding, considering the overall low frequency of flood events, and the inconsistency of their recording through the studied time period, we decided not to perform time and trend analysis on these data.

Agro-meteorological parameters (potential water deficit and Aridity index)

The analysis of the water deficit condition was calculated through the PSMDmax index. Figs 10a, b show the maps constructed using the mean values of PSMDmax for two sub-periods 1961–1990 and 1971–2000, respectively. The areas influenced by a mean water deficit/water surplus during the analyzed periods are highlighted in brown/green. The Marche region is actually not affected with a great water deficit. The areas most affected are located in the coastal bands with mean values of soil water deficit ranging between 10 and 100 mm. Although most of the region shows a water surplus, a noticeable increase of the areas with a water deficit appears in the second sub-period (1971–2000). This is mostly due to (1) the precipitation reduction trend and (2) an increase of the evapotranspiration rate. This last condition is related to the increase in temperatures observed during the 1990s and probably to a cloud cover reduction (Colombo et al. 2007). Furthermore, the water deficit is extending also in valley/low hill areas, especially in the southern part of the region. This is an important finding considering that the southern part of Marche is heavily cultivated and is not directly connected with deep aquifers. An increase in water deficit could cause the necessity to increase irrigation systems and to pump deeper groundwater.

The results of the Mann–Kendall test on annual aridity index values (Fig. 11) show that 67 % of stations are marked by a significant decreasing trend (i.e., drier soil and possible future drought conditions). The areas most affected by this trend are the coastal band and the valley/low hill southern part of the region. On the contrary, the values of the Aridity index calculated for the high hill/mountains stations are much higher than the desertification threshold. This condition is due to the specific geo-morphological characteristics of this area, recording precipitation values greater than 1,100 mm/year (Murri and Fusari 1987) and with trends of annual maximum and minimum temperature lower than those in the rest of the region. This lower temperatures pattern influences directly the potential evapotranspiration and thus the water deficit.

Climate risk perception

The analysis of climate risk perception reveals a good perception and knowledge of the causes and the most likely consequences of climate change. Each of the three

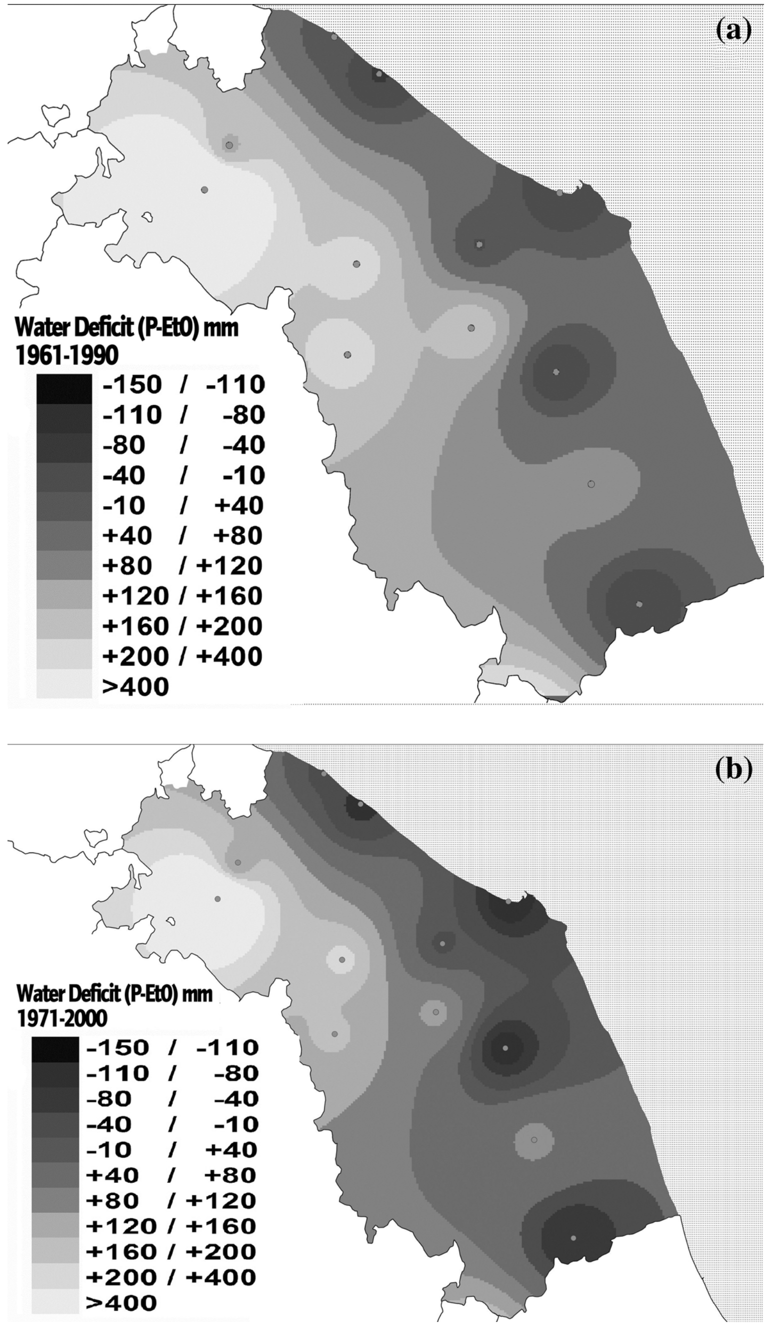

Fig. 10 Mean potential water deficit maximum (PSMD) 1961–1990 (**a**); 1971–2000 (**b**). The areas affected by a mean water deficit/water surplus during the analyzed period are indicated by a *darker/lighter scale*

analyzed groups appeared able to evaluate what will be the most important impacts of climate change in their locale. The interviewed citizens believe that the most likely effects will be an increase of extreme weather events (13 %), desertification (10 %), and floods (8 %). The policy makers are seriously worried with infrastructural damages (19 %) and crop productivity reduction (19 %), while the municipal emergency managers expect a strong increase of the hydrogeological risks (40 %) and augmented burden on the emergency management system (31 %). However, in spite of this relatively accurate assessment of the possible climate change consequences, no concrete or planned actions had been reported by any of the interviewed groups. About 70 % of interviewed residents declare that they are not preparing to deal with the effects of climate change, and 75 % claims that no action had been undertaken by their municipality. Moreover, 94 % of respondents assert that their municipality do not distribute information on how to deal with the local effects of climate change. 24 % of residents believe that the only institution who is preparing to cope with the climate emerging risks is the civil protection system (Table 1).

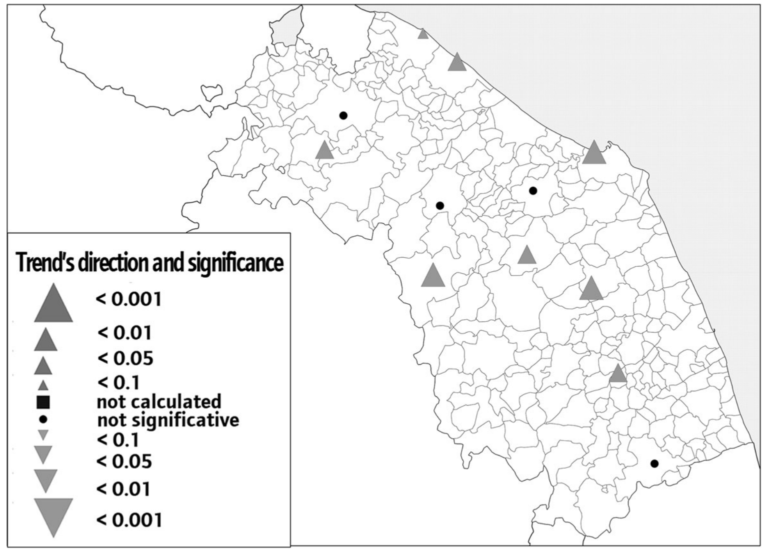

Fig. 11 Trend analysis of annual values of Aridity index. Trends are shown at four levels of confidence: 90, 95, 99, and 99.9 %. The *triangles* size correspond to the trend's level of confidence, whereas the *upper* or *lower vertex* indicates increasing or decreasing changes; stations indicated by *black dots* did not show statistically significant variation. Significant decreasing values of this index specify a tendency toward drier conditions

The lack of specific actions undertaken to prevent and deal with the effects of climate change was further confirmed by the policy makers. Specifically, 66 % of them declare that neither potential future scenarios nor long-term planning in relation to climate change have been developed. Despite this, 86 % of the interviewed policy makers believe that a specific local planning in relation to emerging climate hazards should be adopted, and another 72 % suggests the need of new specific laws on the subject matter. Furthermore, 49 % of the legislators are aware of the lack of public awareness programs about climate change risks.

Finally, 54 % of the interviewed municipal emergency managers believe that the phenomenon must be addressed by public institutions, while 31 % identify the civil protection as the natural coordinating institution. Furthermore, 54 % of them declare that in their municipality, a specific "climate emergency group" is currently preparing to face with emerging climate hazards. The most common activities are forecasting and monitoring, prevention of meteorological events and the purchase of new materials to address potential future hazards. However, 35 % of the municipal emergency managers state that a specific local risk scenario has not yet been developed, thus making it difficult to understand what kind of materials will be most suitable and useful.

The social data analysis also revealed a weak information exchange among citizens, public administrators, scientific community and the civil protection system, making it difficult the construction of shared strategies of action. As a matter of fact, 81 % of emergency managers declare that there is no effective collaboration with scientific institutions, whereas 57 % of policy makers maintain that there is an active collaboration with the scientific community, in spite of the difficulties of the public administration access scientific resources.

Discussion and conclusions

Results showed relevant changes affecting the atmospheric, marine, and soil environments. Such changes are often interconnected and may affect in different ways the society. For example, temperature variations show a more significant and larger trend in spring and summer, which along with annual precipitation reduction could lead to an increase of soil aridity. Indeed, the agro-meteorological indexes (Figs. 10, 11) confirm a decrease of water availability in the soil. Moreover, the markedly decreasing trend of winter precipitation would further deplete the underground water reservoir and increase forest fire hazards. It should be said that this condition of decreasing water availability appears to be widespread and affecting not only the study area, the Marche region, but also the Italian northern plain (Brunetti et al. 2000a). Actually the Po River discharges show decreasing trends in all seasons except in autumn. The strong reduction of winter precipitation observed in northern Italy affects the Po River discharge in winter and concurs to its most relevant decrease in spring (which is also due to the reduced snowfall on the surrounding mountains).

Among the most evident consequences of precipitation and rivers discharge reduction is an increase of surface salinity in the northern Adriatic Sea evident in spring and particularly marked in summer. On the contrary, a substantial surface salinity decrease is observed in autumn and winter. Certainly, this winter surface salinity decrease in the Northern Adriatic, contrasts with the above observed reduction of rainfall and discharge of the Po River. Likely, this winter salinity decrease is an effect of slower marine system response and of areal averages. In fact, maps of seasonal salinity anomaly over the northern Adriatic area (Russo et al. 2002) show around the Po River Delta: (1) a very large salinity decrease in autumn, due to the increased discharge of the Po River, and (2) a salinity increase in winter due to the decreased discharge of the Po River. Notwithstanding, the remaining part of the northern Adriatic basin show a winter salinity decrease, due to the spreading of large amount of freshwater discharged in autumn. Hence, the average surface salinity of the northern Adriatic basin decreases in winter.

Moreover, this long-term study highlighted significant environmental modifications in the northern Adriatic Sea. Results show that the northern Adriatic Sea during the last two decades has been influenced by significant warming of air temperature, changes in precipitation pattern, and a varying Po river runoff, and these changes are likely producing variations of marine properties. Regarding the observed general decline of river runoff in this area, Cozzi and Giani (2011) predicted that if the most recent trend will continue during the next decades, a reduction of 1 % per year of the northern Adriatic rivers runoff might be experienced. The northern Adriatic is one of the most productive areas of the Mediterranean Sea, and changes in its physical and chemical characteristics influencing its marine biota could have important consequences on human activities. In this area, important changes are reported in plankton organisms (e.g., a reduction of the phytoplankton biomass and a general trend toward small-size species, together with a reduction in the intensity and frequency of late winter diatom blooms; changes in microzooplankton community composition, a mesozooplankton increase both in number of individuals and in biomass), while macrobenthos showed recovery in areas previously impacted by eutrophication and a relevant spreading of nonindigenous species (Giani et al. 2012).

As the sustainability of fisheries in the Adriatic Sea depends on fishing pressure, annual recruitment success, availability of food, and water quality, it is very important to understand how climate changes could affect fish populations. These environmental changes could have important impact on fish abundance and community composition, but also on modification of nursery areas, changes in juvenile survival, and lack of synchronization between predators and preys (Giani et al. 2012). To this extent, Santojanni et al. (2006) reported that changes in environmental conditions, particularly river discharges, influence the recruitment of anchovy (the most caught commercial species) in the northern and central Adriatic. Likewise, the on-going warming trend and changes in rivers discharge, in this shallow sea, could cause important consequences on oxygen concentrations and plankton and benthos community structures. Other scientists have already reported an increase of thermophilic species, most of them allochtonous, expanding northward (Francour et al. 1994; Dulčić and Grbec 2000; Dulčić et al. 2004; Azzurro et al. 2011), and decrease or disappearance of some previously abundant cold-water fish species (Bombace 2001; Grbec et al. 2002). An important decreasing trend has been recorded for total biomass of target demersal fishes and for small pelagic fish catches (Grbec et al. 2002; Coll et al. 2010; Giani et al. 2012).

Considering the global and regional climate projections, the above-mentioned trends will likely continue in the current century affecting both the land and marine domains. Among the possible consequences are agricultural and social droughts, fishery yield reduction, coastal areas desertification and erosion, soil degradation, invasive species (both animal and vegetal), harmful algal blooms, spread of new diseases, heat waves, as well as hydrogeological hazards. Remarkably, these climate hazards appear to be known and most feared by the local residents. However, slight differences are present among different segments of society. For example, the policy makers appear concerned with the reduction of agricultural productivity and infrastructural damages. On the contrary, emergency managers and residents were mostly worried about the increase of extreme weather events, which possibly will have the most direct impact on citizens' life and civil protection activities.

Noteworthy, is also the fact that in spite of such an accurate awareness, as of today, few preventive and protective actions have been planned or implemented. Thus, it becomes pivotal the strengthening of collaboration and communication among scientific community, policy makers, emergency managers, and residents to define and implement effective adaptation policies and preventive measures. In conclusion, it can be said that this study further proves the multidisciplinary dimension of the climate issue, which can be successfully tackled only through a holistic approach and by sharing the challenge of climate change adaptation among the various components of society.

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