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Stepped water warming effects on coastal ecosystem dynamics as monitored from fixed mooring stations in NW Mediterranean Sea

Nixon Bahamon[1, 2], Jacopo Aguzzi[1], Miguel Ángel Ahumada-Sempoal[3], Joan Baptista Company[1], Charlotte Reuschel[4], Francesc Peters[1], Raffaele Bernardello[5], Joan Navarro[1], Zoila Velásquez[6], Antonio Cruzado[6]

[1] *Instituto de Ciencias del Mar – CSIC, Barcelona (Spain), n.bahamon@csic.es, jaguzzi@icm.csic.es, batista@icm.csic.es, cesc@icm.csic.es, joan@icm.csic.es*

[2] *Centro de Estudios Avanzados de Blanes – CSIC, Blanes (Spain)*

[3] *Universidad del Mar (Mexico)-CSIC, Puerto Ángel (Mexico), ahumada@angel.umar.mx*

[4] *Fresenius University of Applied Sciences, Idstein (Germany), reuschel.charlotte@stud.hs-fresenius.de*

[5] *Barcelona Supercomputing Center, Barcelona (Spain), raffaele.bernardello@bsc.es*

[6] *Oceans.cat, Blanes (Spain), acruzado@oceans.cat*

***Abstract* – Average global land and ocean surface temperature has stepped up since 2014 above the average. The Mediterranean Sea temperature follows this global trend. The effects of the warming on coastal areas in the Mediterranean are worrying, as they are biodiversity hotspots. Atypical warmer summer periods in the Mediterranean have been pointed out as potential drivers of massive mortalities of deep-sea organisms. Multi-sensor mooring arrays are fundamental to assess the magnitude and effects of water warming. Analysis of long-term oceanographic and biogeochemical data collected in two fixed coastal observation stations in northwestern Mediterranean Sea reveals that marine oligotrophy has intensified since 2014, with increasing water temperature by 0.25°C, greater transparency and an earlier starting of the summer conditions. Phytoplankton biomass and nutrients show no apparent change of trends. Further studies are required to assess an eventual mismatch between the life cycles of the organisms and the expected environmental conditions. These fixed stations may be considered as reference monitoring locations to assess the effects of water warming on marine ecosystem functioning.**

I. INTRODUCTION

Global Ocean warming is escalating at unprecedented rates what in turn causes the marine environment and living resources to come under increasing stress [1]. Since 2014, global land and sea surface temperature has scaled 0.16°C above the last decade average, representing about 18% of the 0.9 °C temperature increasing since 1900 to 2013 [1]. Though high temperature anomalies in 2015 and 2016 were partially explained by El Niño event [2], temperature anomalies in 2017 and 2018 were not attributable to El Niño, thus the scaled warming starting in 2014 may not be transitional. The Mediterranean Sea surface temperature has been following the average global trend with water temperature stepping by 0.30°C between 2014 and 2017 [3].

The impact of increasing water-warming rates on the dynamics of coastal ecosystems is being remarkable, as the continental shelf holds highly sensitive biodiversity. Water temperature may be overpassing the upper thermal thresholds of living organisms [4], affecting survival, growth and reproduction [4, 5] as for the case of octocorals and gorgonians [6]. Long-lasting positive extreme temperatures have caused mass mortalities events of invertebrates in the Mediterranean Sea [7].

Longer and warmer summers may expand oligotrophic areas of the ocean [8] due to surface heating, what in turn reinforces the thermocline and makes the mixed layer thicker [9]. The strengthening of the thermocline may slow down the nutrients supply toward the euphotic zone from deeper water layer makes, thus lessening the overall phytoplankton biomass production [9, 10]. A long-lasting thermocline may also prevent the vertical mixing of the water column, which in turn constrains the winter phytoplankton bloom to shorter periods [11]. Considering that the upper limit of the thermocline layer in summer in NW Mediterranean Sea is very shallow around 30 m depth [9], a significant impact of sea surface warming is expected to take place not only on the thermocline strength and depth, but also on the life cycles of relatively shallow-living pelagic and sea-floor organisms.

Long-term coastal monitoring stations collecting atmospheric, oceanographic and biogeochemical data from the water column are fundamental to assess the effect of environmental changes on the marine ecosystem. In the present study, historical data collected during nearly a decade by the Operational Observatory of the Catalan Sea (OOCS) in NW Mediterranean [12], were used to assess the impact of the coastal water warming on the ecosystem functioning.

II. METHODS

The OOCS operated uninterruptedly from March 2009 to March 2018, collecting in-situ physical and biogeochemical data from two fixed observation stations over the continental shelf in the Blanes canyon head (2.7 miles offshore; 230 m depth) and in the Blanes bay (0.5 miles offshore; 20 m depth) [Fig. 1]. The stations were monitored with instrumentation on-board a research boat at fortnightly basis, i.e. CTD profiles and discrete samples for analysis of nutrients, chlorophylls and picoplankton, along the water column. The CTD profiles at the canyon station were used to estimate the mixed layer depth (MLD). An anchored oceanography buoy in the canyon station collected simultaneous data at hourly basis, from meteorological sensors, i.e. air temperature, humidity, radiation and winds, and from oceanographic multisensors (CTDs) i.e. water temperature, salinity, visible radiation, fluorescence and turbidity, attached to the mooring line of the buoy at 1, 25 and 50 m depths [12]. Net air-sea heat fluxes were estimated from the buoy instrumentation data and reanalysis products from NOAA (sea surface albedo and cloud cover).

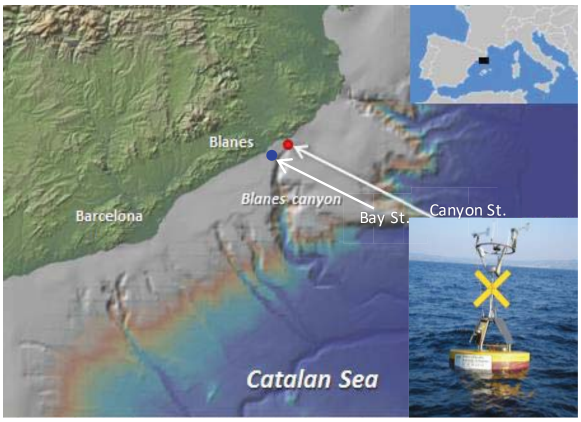

Fig. 1. Observation stations of the OOCS. The inshore station is located in the Blanes bay (blue point). The offshore station with an anchored oceanographic buoy is located in the Blanes canyon head (red point).

III. RESULTS AND DISCUSSION

The analysis of time-series of the marine environmental conditions over the continental shelf in the Catalan Sea revealed that some physical and biogeochemical properties of the water column have been subject to particularly stressing oligotrophic conditions since 2013/2014. For the period 2014 – 2017, average water temperature raised by 0.25°C, over the decadal average [Fig. 2], in line with the stepped global warming pattern [2].

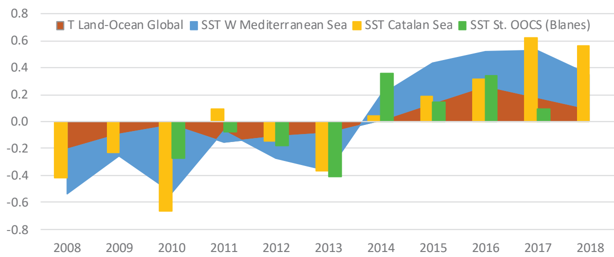

Fig. 2. Temperature anomalies at different spatial scales from global to local at the observation station in the Blanes Canyon head (offshore OOCS station).

Since 2013, i.e. one year before the stepped warming starting, average shifting times of total air-sea heat fluxes (Q_T) from negative to positive, i.e. water warming, $Q_T > 0$, and from positive to negative, i.e. water cooling, $Q_T < 0$, have moved back in time by about two weeks [Fig.3]. Nevertheless, the duration of the summer period remained unchanged around 170 – 180 days, which made the yearly heat budget to remain around the historical average, slightly above zero. Accounting for the advective heat fluxes over the same location in further studies, will adjust the present estimates of heat fluxes.

An overall trend of the average MLD in winter to get deeper was observed all over the period until 2016, with a change of trend in 2017 [Fig.4]. Since 2014, the duration of the MLD was about 2.5 months, exceeding the average

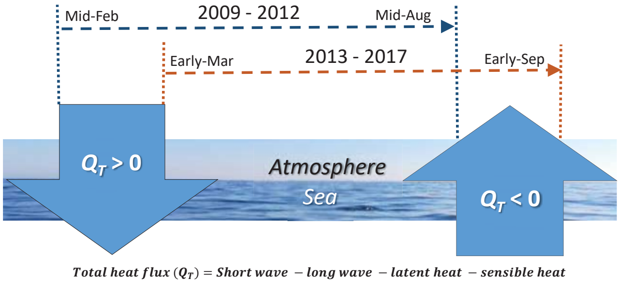

Fig. 3. Representation of the shifted starting summer times, as estimated from sea surface heat fluxes (Q_T) with sensors and probes in the oceanographic buoy anchored in the Blanes canyon head.

duration for the period before 2014 (not shown here). These findings seem counterintuitive to the overall water warming and are probably due to the loss of heat during this period combined with the intensification of winds.

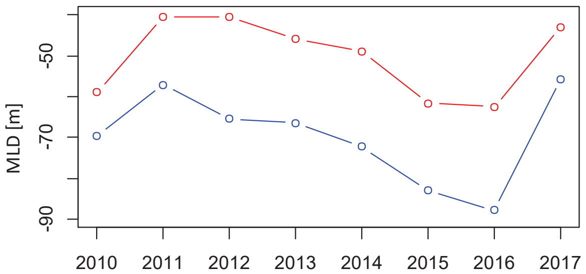

Fig. 4. Winter MLD estimated from 10 m reference depth for $\Delta\sigma_\theta$=0.03 kg/m^3 (red line) and ΔT= 0.2°C (blue line).

The analysis of vertically integrated biogeochemical properties over the water column [Fig. 5] revealed that phytoplankton biomass (chlorophylls) generally remains unaltered by water warming, though the temporal pattern of nearshore surface chlorophylls may be responding to stronger local stratification conditions. Additionally, the turbidity measurements suggested that the water column is becoming more transparent (i.e. less turbid) since 2014, being more noticeable in the nearshore station since 2015. For the case of the nitrate concentration, relatively high inter-annual variability with no significant trend was found.

As climatic predictions suggest the anomalously warming conditions recorded during and after 2014 will extend during 2018-2022 [2], strengthening of the oligotrophic conditions of coastal waters with negative impacts on the biology and ecology of pelagic and sea-floor species is expected. Records of e.g. massive mortalities of sponges [13, 14], gorgonians [15], bivalves [16] and other benthic invertebrates [7] are indicative of the expected consequences of pronounced oligotrophic

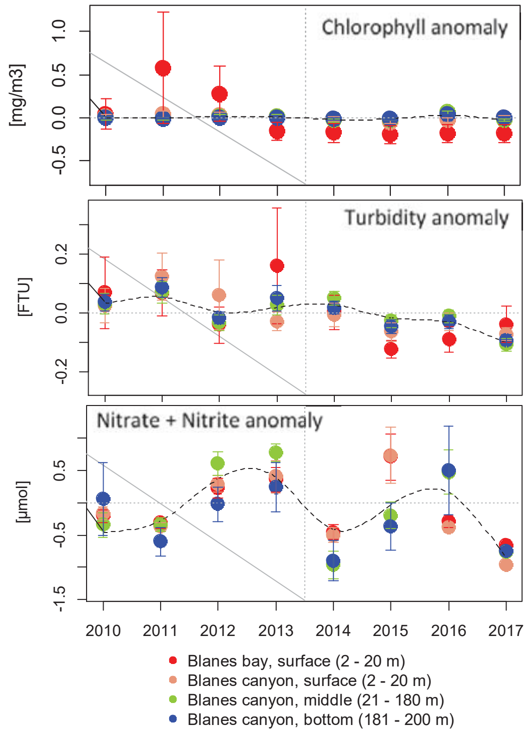

Fig. 5. Depth-integrated anomalies (with error bars) of biogeochemical properties of the water column.

conditions.

The intensification of the marine oligotrophic conditions and the direct impact on marine life is just one of the consequences of increasing rates of seawater warming. Ocean warming is also contributing to increase the strength and frequency of hurricanes, tropical storms and floods [17]. Another consequence is the sea level rise at unexpected rates, due to the thermal expansion and to the melting ice [18]. Weakening of the global circulation may be also be taking place particularly in winter and spring [19], with unclear consequences for regional and global climate. Notwithstanding the importance of monitoring the seas and oceans, there remain under-sampled as deduced from relatively low number of monitoring stations preventing more accurate understanding of the current and historical changes, and limiting providing more reliable forecasting. Long-term monitoring in coastal and open sea areas with diverse in-situ and remote array of sensors are fundamental to assess at which extend the oceans are being altered by global warming and how those changes affect marine life, natural resources and human life.

IV. CONCLUSIONS

The strengthening of the oligotrophic conditions over the continental shelf [Fig. 6] because of combined effects

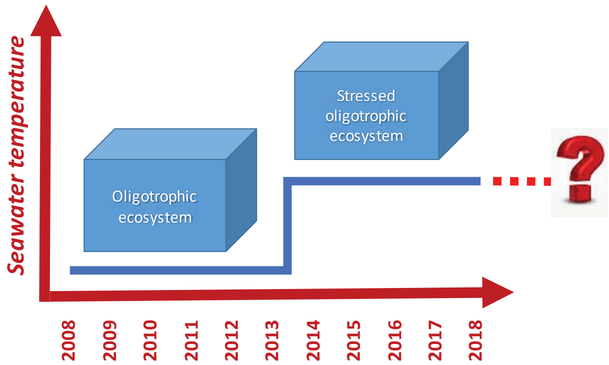

Fig. 6. Representation of stepped stressing oligotrophic conditions of marine ecosystems due to water warming in the last decade.

of stepped water heating, early starting of summer conditions, increasing water transparency and deepening of the winter mixed layer, should be considered in further studies on the dynamic of pelagic and benthic species. The environmental changes may be producing a mismatch between the life cycles of the organisms and the likely environmental conditions [20].

Marine observatories integrating measurements of physical and biogeochemical properties of the air-sea interface and water column are helpful to assess the diverse effects of water warming on the marine environment. The present findings may apply to other temperate oligotrophic areas subject to similar environmental stressors.

V. AKNOWLEDGEMENTS

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