Cross-shore environmental gradients in Mediterranean nearshore waters

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ABSTRACT

During summer, when oligotrophic conditions prevail offshore in the Mediterranean Sea, an alongshore zone with enhanced phytoplankton biomass is often evidenced in these waters. Here, using high continuous measurements of temperature, salinity and fluorescence as well as discrete samples and primary production experiments, we examine the cross-shore typology and the associated chemical and biological characteristics of these waters. Data from three coastal regions in the NW Mediterranean revealed widespread presence of lower water density bands in the proximity of the shoreline generated by increased warming and groundwater seeps through the coastal sediments. Most often, enhanced phytoplankton biomass (max=9.6 mg Chla m^3; up to 16 fold offshore chlorophyll) was associated with these modified waters and exponentially decayed in the offshore direction. Gradient characteristics are highly variable but the main onshore-offshore features, determined by terrestrial loads and hydrodynamics are locally consistent. Important variations were observed in the structure of the communities among nearshore sites which were attributed to variations in the geochemical conditions. Our study argues the relevance of the formation of a groundwater-sustained nearshore niche and its temporal stability for the development of a distinct community which could eventually favor the emergence of harmful algal blooms.

INTRODUCTION

Ecologically, nearshore waters represent a system that is maintained in a state of non-equilibrium by the continuous contribution of matter and energy from the terrestrial and benthic systems. This results in a highly dynamic and productive region that it is also very sensitive to disturbances, either natural or anthropogenic, being relevant in the transport of nutrients, plankton, spore and larval dispersal and settlement as well as in the dispersion of contaminants [1, 2, 3]. Indeed, nearshore waters contribute significantly to land-ocean biogeochemical processes and are relevant to the maintenance of the early life stage development of many marine organisms and overall diversity [4].

It is hypothesized that nearshore assemblages in which high biomass blooms develop are composed by phytoplankton taxa that can rapidly use enhanced inputs of nutrients prevailing over slower growing populations. Such shifts in populations at the primary producer level can deeply modify the complex interactions within the food web [5]. Nevertheless, it is unclear to which degree these plankton assemblages inhabiting the nearshore environment constitute an isolated and ecologically differentiated entity or if the nearshore green band is part of a continuum composed by same assemblages as the adjacent offshore marine communities proliferating in the nearshore enriched waters.

Identifying the existence of cross-shore environmental gradients and the mechanism that intervene in their formation are basic but important steps to understand anthropically mediated variations in carbon balance and nutrient cycling processes in the coastal ocean. It is also provides insight on the development of coastal harmful algal blooms (HABs). In this study, we seek to conceptualize how physico-chemical gradients shape the distribution and abundance, of nearshore phytoplankton communities and to identify the relevant forces, constraints and mechanisms that shape these patterns.

MATERIAL & METHODS

Sampling took place between June and July 2014 and 2015 in the coasts of Mallorca and Catalonia. 52 underway cross-shore transects were sampled from some 3 km off the shore to the shoreline (~0.4 m depth) during good weather conditions and calmed seas. Continuous measurements of temperature, salinity and fluorescence were obtained using an integrated system composed by a SBE 45 MicroTSG thermosalinograph, an Enviro-T in-line fluorometer. Data was captured at 1 Hz and merged with the GPS position and echosounder depth. Surface (~0.4 m depth) seawater was pumped at a rate of (1.5 L min-1) with a submersible pump attached to the side of the boat at a depth of 25 cm.

Between 7 and 10 discrete samples were obtained along selected transects. Concentrations of dissolved inorganic nitrogen, phosphate and soluble reactive silicates were measured following [6]. Size-fractionated chlorophyll concentrations were determined by fluorometry of acetone extractions. Samples were physically separated in three size ranges: picoplankton (<3 µm), nanoplankton (between 3 and 10 µm), and microplankton (>10 µm) collected through 25-mm Whatman GF/F glass-fiber filters (2 replicates per sample) that were stored frozen. The autotrophic organisms were identified through either microscopic or flow cytometric analyses. Determination of pico- and nanoplankton abundance was done by Becton and Dickinson flow cytometer. For microplankton enumeration, 50 ml aliquot was settled in a microscopic chamber and an appropriate area of it was scanned using a Leica-Leitz DM-II inverted microscope.

In one of the surveyed areas (Palma Bay), net community production, community respiration and gross production were determined by the oxygen method in triplicate subsamples. Net community production was estimated as the difference between the light and initial bottles; community respiration as the difference between the initial and dark bottles; and gross production as the difference between the light and dark bottles.

RESULTS & DISCUSSION

High solar irradiance and reduced mixing rates during this season favor stratification and the formation of a diurnal skin-layer thermocline in coastal waters. Our data reveals widespread existence of green bands in nearshore waters of the Mediterranean Sea. The limit of this enhanced biomass strip can extend up to 1200 m from the shoreline. However, most typically (85% of the transects), it is restricted to the first 500 m due to the influence of wind-induced shoreward transport.

With some exceptions, slight salinity declines (0.1 to 0.8) were observed in most of the recorded suggesting the importance of groundwater seeps in the nearshore water biogeochemistry. Dissolved inorganic nutrient concentrations did not correlate well with salinity suggesting that nutrient concentrations are not good tracers of groundwater discharges in places where terrestrial flux is slow and diffuse. However, increases in nitrate and occasionally in silicate were observed at sampling points. Conversely, inorganic phosphate was typically low (<0.11µmol L−1).

Chlorophyll concentrations near the shore (~1m depth) ranged from 0.78 to 9.58 mg m^3 whereas mean background (offshore) chlorophyll levels were 0.45±0.28 mg m^3. This nearshore enhancement was paralleled by increases in large phytoplankton cells (>10 µm) including dinoflagellates and flagellates. In this nearshore band, primary production reached 817 mg C m^{-3} d^{-1}. In contrast, surface phytoplankton community at the offshore transect boundary was dominated by cells less than 3 µm in size, such as the cyanobacteria *Synechococcus* spp. In these waters, the <3 µm size fraction accounted for 65 and 70% of the total chlorophyll and near-surface primary production was 14 mg C m^{-3} d^{-1}

Repeated transects at the same point showed large daily variations in nearshore biomass (one order in magnitude) which were attributed to the combined effects of vertical migration of microorganism and wind induced cell accumulation. In a system where a large proportion of coastal dynamics is fundamentally forced by wind, shore-directed thermal winds have direct influence on the generation and persistence of nearshore green bands.

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