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Production, exportation and preservation of silicoflagellates in Alfonso Basin, Gulf of California

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ABSTRACT

Limited areas of sea floor have the physiochemical conditions that allow for the formation and preservation of high resolution (yearly or close to yearly) laminated sediments that can function as a historic proxy for past oceanographic and climate conditions. We evaluated and established the fidelity of the sedimentary record in recording these signals by analyzing silicoflagellates production, changes in species composition, skeletal settling and their subsequent burial in bottom sediments at Alfonso Basin. The data series from December 2005 to February 2008 showed similar tendencies in both the vertical flux and overlying euphotic zone (Z_{eu}) production of silicoflagellates. Both series were numerically dominated by *Octactis pulchra* with maxima values being recorded for the mixed water column period. Observed differences occurred during the studied years in both magnitude and in flux composition. The presence of a mixed assemblage with (warm–temperate–cold) species such as *Dictyocha fibula* var. *robusta*, *Dictyocha epiodon* and *Distephanus speculum* could be explained by a synchronization of trends between a predominantly positive Pacific Decadal Oscillation and a positive North Pacific Gyre Oscillation climate phases that were the background conditions underlying the early 2006 through 2007 El Niño event. A Morisita's similarity index value of 97.5% between winter trap and Z_{eu} samples combined with an annualized settling factor of 0.45, suggests that Alfonso Basin is a favorable settling environment for silicoflagellates. However, core-top sediments showed an attenuation of record fidelity (burial factor = 0.25) resulting in a modified record for the production and settling of skeletons. *O. pulchra* that were not preserved in sediments as the dominant species and with this removal, the signal was also lost of the highest silicoflagellate production season (Mixing-cyclonic eddy periods) from the sedimentary record of the Alfonso Basin.

1. Introduction

Biological production in the euphotic zone (Z_{eu}) of coastal environments is strongly influenced by physical processes such as light availability (seasonal and latitudinal), complex circulation patterns, water column stratification, wind stress, tidal mixing (Smetacek, 1985, 1999; Garg and Bhaskar, 2000; Lange et al., 2000), entrainment of new nutrients as well as chemical and biochemical processes involving in regenerate nutrients from organic matter found in the water column and underlying sediments (Kiørboe, 2001; Canfield et al., 1993). There is a general dissociative conclusion to processes that occur in the Z_{eu} is that, photosynthetically derived organic matter is mineralized with a fraction of this biogenic material exported out of this layer (e.g., Alldredge and Gottschalk, 1990; Kiørboe and Hansen, 1993; Kiørboe, 2001; Buesseler et al., 2007).

A growing understanding, achieved during the past 30 years, of the Z_{eu} biogenic material settling dynamics can be attributed to sediment trap studies (Honjo et al., 2008). The results have illustrated, the importance of siliceous phytoplankton (diatoms and silicoflagellates) as ballast during the gravitational settling of biogenic aggregates (Honjo et al., 2008). Vertical fluxes of silicoflagellate skeletons are particularly suitable in linking export production derived from surface production to the sedimentary depositional record, since a greater proportion of silicoflagellates that arrive at the bottom are integrated into the sedimentary record (Schrader et al., 1986).

While trapping experiments have provided important information in understanding the dynamics of the biogenic settling material, there are still some inconsistencies in the precision of the productivity signal recorded by sediment traps, especially in areas of low productivity (Sancetta, 1992). In these areas it has been evidenced that most of the photo-synthetically produced organic matter is transformed by heterotrophs or the chemical environment before they can settle to the bottom (Kiørboe, 2000, 2003; Grossart et al., 2006; Azam and Malfatti, 2007). This demonstrates the necessity for integrated studies that connect

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production, settling and preservation of siliceous phytoplankton; which then can be examined as a first order approximation of historic pelagic ecosystems reconstructed from sedimentary record. These reconstructions necessitate linkage to counterpart studies of the upper water column combined with sediment trap experiments and finally their evaluation with the sedimentary record to forge an encompassment determining the accuracy as well as validity of the sedimentary record as a historic register of plankton production in the upper ocean with time scale resolution on the order of days to months (Romero et al., 1999).

The vertical flux of siliceous organisms has been studied in several regions of the world (e.g. Takahashi, 1987, 1991; Thunell et al., 1996; Treppke et al., 1996; Thunell, 1998; Romero et al., 2001, 2009; Osawa et al., 2005; Onodera and Takahashi, 2012; Martínez-López et al., 2012). In the central and southern region of the California Current System (CCS) a number of studies have documented, variations in siliceous fluxes on both seasonal and interannual time scales (Lange et al., 2000; Venrick et al., 2003; Martínez-López et al., 2010). However, in the Gulf of California such investigations are scant (Sancetta, 1995; Thunell et al., 1996; Thunell, 1998; Martínez-López et al., 2012). Silicoflagellates preserved in the sediments have been proved particularly useful, in the reconstruction of paleoclimatic and paleoceanographic scenarios in this area with resolutions on the decadal to millennial scales (Schrader and Baumgartner, 1983; Leclerc and Schrader, 1987; Barron et al., 2004; Barron and Bukry, 2007). However, understanding of silicoflagellates ecology in the Z_{eu} in this region is very limited.

The present study is the first to relate hydrological changes in the water column to vertical particle fluxes and their subsequent preservation in this basin's sedimentary record. The essential, but unavailable information to form these linkages is; distribution and seasonal succession of taxa in the euphotic zone and the relationship between the silicoflagellates species and temporal environmental variability.

2. Methodology

2.1. Alfonso Basin

Alfonso Basin is a small, closed marginal basin with a maximum depth of 415 m located in the northern sector of the Bay of La Paz. It has been classified as a slope basin produced by extensional tectonics in a borderland type margin setting (Nava-Sánchez et al., 2001) that preserves high resolution Holocene sedimentary sequences with laminated structure (Pérez-Cruz, 2006; González-Yajimovich et al., 2007). At 275 m depth there is a bathymetric sill, which induces and preserves low oxygen content by preventing deep, oxygen-rich Gulf waters from entering the basin, thus maintaining low oxygen bottom-waters ($O_2 < 0.1$ ml/l) (Monreal-Gómez et al., 2001). The Alfonso Basin receives sediments from small local drainages carved into the steep east face of tilted volcanic blocks of the Comondu Formation that form elongated mountain ranges that dominate this part of the Baja California Peninsula (Nava-Sánchez et al., 2001; Pérez-Cruz and Urrutia-Fucugauchi, 2010).

The Alfonso Basin area is influenced by Northwest winds, which increase in strength from November to May (Robles-Gil Mestre, 1998), whereas southern winds prevail from June to October punctuated by sporadic tropical depression/hurricane episodes. During autumn the equatorial–tropical north poleward flowing Inshore Countercurrent is present (Baumgartner and Christensen, 1985). La Paz bay interchanges water masses with the Gulf principally through the main entrance (Boca Grande), located in its northeastern extent. Water masses involved are the Tropical Surface Water (TSW), the Gulf of California Water (GCW) and Subsurface Subtropical Water (SsStW). The TSW (predominantly above the thermocline) and the SsStW enters the Gulf of California (GC) from the Pacific Ocean. TSW flows from the gulf to the bay, once there, due to evaporation processes; TSW increases its salinity above 35 thereafter transitioning into GCW (Monreal-Gómez et al., 2001).

The most important feature of La Paz Bay's hydrographic regime is a recognized cyclonic eddy (CE) (Monreal-Gómez et al., 2001; Obeso-Nieblas et al., 2002; Salinas-González et al., 2003) (Fig. 1). This eddy (CE) produces isopycnal uplifting that results in entrainment of subsurface water nutrients into the photic zone, which in turn regulates the primary productivity at the site (Villegas-Aguilera, 2009; Martínez-López et al., 2012; Verdugo-Díaz et al., 2014). Colder conditions appear in the central eddy in late April generally disappear by early July, thus demarcating the life span of the cyclonic circulatory episode (Hakspiel-Segura, 2014). Derivational effects resulting from its proximity to the juncture of Gulf of California and the open Pacific Ocean is that, the basin functions as a sensitive recorder of regional variations in the Gulf as well as low-frequency, high-latitude Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO), and also low latitude high-frequency El Niño signals (Baumgartner and Christensen, 1985; Badan-Dangon et al., 1991; Pavia et al., 2006; Lluch-Cota et al., 2010; Martínez-López et al., 2012). The complex interaction of these signals has a strong influence on the oceanography, and species abundance and distribution at this site.

2.2. Sampling

2.2.1. Water column samples

Monthly surveys were conducted for the period December 2005 to February 2008 at the sediment trap site. During each visit Conductivity/Temperature/Depth (CTD) profiles were recorded from the surface to 100 m. Water samples were collected with 5-L Niskin bottles from seven optical depths (100, 55, 33, 10, 3, 1 and 0.1% I_o, that which were previously determined using a Secchi disk) to evaluate dissolved inorganic nutrients (NO_3^-–N, NO_2^-–N and SiO_2–Si) and chlorophyll a (Chl *a*) according to Strickland and Parsons (1972) and silicoflagellates species quantifications. Abundance and composition of silicoflagellates were determined under an inverted microscope (CK2 Olympus) fitted with phase contrast. Counts were performed at 400× and 1000× magnification, using 1% Lugol's solution pre-acidified to ~pH 7 to prevent dissolution of silica according to the standard technique of Utermöhl (Hasle, 1978) and following the silicoflagellate taxonomy of Murray and Schrader (1983) as updated by Schrader et al. (1986). Silicoflagellate depth abundances were compiled to be used in calculating the totals for the depth-integral values (cell m^{-2}) for the Z_{eu} (surface to 0.1% I_o depth) by standard trapezoidal integration method.

A multivariate analytical procedure was used to compare silicoflagellate sediment trap data to water sample data. The number of variables included in the analysis was decreased, by selecting only the most frequently observed species (those occurring in at least 10% of the samples). The data matrix generated was used for a Q-mode cluster analysis after a Log $(x + 1)$ transformation.

2.2.2. Sediment trap samples

A Technicap Model PP3 sediment trap was deployed at 360 m depth (≈60 m from bottom) in the deepest part (420 m) of Alfonso Basin (Lat. 24° 35′ N, Long. 110° 36′ W) (Fig. 1) The trap was programmed to have a sample collection period of 8 to 17 days between December 2005 to February 2008 (dependent on vessel availability to recover, service and redeploy moored trap) cycling through the 12 acid-washed collecting bottles (filled with filtered seawater with an additional 5 g kg^{-1} of reagent grade NaCl and enough formaldehyde to produce a 4% buffered formalin solution).

Upon recovery, the trap samples were handled as described in Silverberg et al. (2006). The bulk sample (without swimmers) was then split into 10 subsamples (splits) using a rotary splitter modeled after Honjo and Doherty (1988). Fluxes were calculated as a function of the sampling period (days) and the area of the trap opening.

The 1/10 subsample for silicoflagellates was rinsed in distilled water and centrifuged several times in order to remove salts and preservative. The entire aliquot was placed in a 15 ml graduated test tube and cleaned