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Fluctuations in export productivity over the last century from sediments of a southern Chilean fjord (44°S)

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Abstract

Here we present the first reconstruction of changes in surface primary production during the last century from the Puyuhuapi fjord in southern Chile, using a variety of parameters (diatoms, biogenic silica, total organic carbon, chlorins, and proteins) as productivity proxies. Two sediment cores from the head and the center of the fjord were analyzed and compared to gain insights on past changes in productivity in these two different depositional environments. Higher sedimentation rates found at the head of the fjord result from the combination of a shallower water column and a restricted circulation by the occurrence of a sill. Additionally, sediment mixing depths estimated from ^{210}Pb data suggest that suboxic conditions may dominate the bottom water and the sediment–water interface in this location.

Productivity of the Puyuhuapi fjord during the last century was characterized by a constant increase from the late 19th century to the early 1980s, then decreased until the late 1990s, and then rose again to present-day values. The influence of rainfall on productivity was most noticeable during periods of low rainfall, which coincided with decreased overall productivity within the Puyuhuapi fjord. Simultaneous variations in productivity and rainfall in the study area suggest that marine productivity could respond to atmospheric–oceanic interactions at a local scale. At a regional scale, marine productivity of the area may be related to other large-scale processes such as the El Niño Southern Oscillation.
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1. Introduction

Pelagic productivity plays an important role in the transfer of carbon from the atmosphere to the sediments through the biological pump (Berger et al., 1989).

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Although organic matter preserved in marine sediments is mainly derived from exported material biosynthesized by marine organisms inhabiting the ocean's surface waters, terrestrial organic matter can also be found along continental margins (e.g., Wakeham and Lee, 1993; Hedges and Keil, 1995; Hedges et al., 1997). The flux of organic matter to marine sediments is controlled by primary production, heterotrophic degradation, water column depth, and advective transport (e.g., Wakeham and Lee, 1993), whereas preservation in the sedimentary record is mainly affected by sediment and organic matter accumulation rates, bottom water oxygen, organic matter sources, and adsorption onto mineral grains (e.g., Hedges and Keil, 1995). The biological signature preserved in the sedimentary record, discrete organisms as well as elemental and molecular proxies, is useful to determine past changes in productivity and to infer possible causes of its variation.

The sediment geochemistry of the Chilean fjords (south of 41 °S) has received attention in the last decade, mainly with the support of the Chilean Cimar-Fiordos Program (National Oceanographic Committee) in the area between Puerto Montt (42 °S) and Cape Horn (56 °S). These studies, however, have focused mostly on the geochemistry of surface sediments (e.g., Ahumada et al., 1996; Silva et al., 1998; Silva and Prego, 2002). Downcore records of organic compounds are scarce (e.g., Rojas and Silva, 2003) and a lack of studies on paleoceanographic processes is evident.

Relatively high sedimentation rates characterize the Chilean fjord region (Rojas, 2002; Salamanca and Jara, 2003) and allow recovery of records with decadal or sub-decadal resolution, favoring paleoceanographic studies, as a result of ocean–atmosphere interactions occurring at those time scales. This area is under the influence of the main Southern Hemisphere atmospheric circulation pattern, the Southern Westerlies, which in turn, are closely linked to changes within the tropical climate system and climate conditions in coastal Antarctica (e.g., Lamy et al., 2001). Thus, this region is critical for clarifying the synchronicity in the interhemispheric timing of high latitude climate change and its connections with tropical and subtropical areas. Moreover, the combination of geographical location (see below) and high primary productivity (e.g., Astoreca et al., 2002) makes this area suitable to study changes in past export production originating from changes in both the paleo-Patagonian ice caps and the globally important Southern Ocean. The main anthropogenic influence in the area started with the establishment of the first towns in Chile's XI region (~46–46 °S) in the early XX century; industrial activity began in the last decade with rapidly growing salmon farming.

This study addresses issues of paleoceanography and climate change during the last century in a still-pristine area influenced by the Westerlies and which will undergo significant anthropogenic alterations in the near future as salmon farming expands. We present the first reconstruction of changes in export production from the Puyuhuapi fjord and show that the most remarkable decreases in overall productivity seem to be associated with periods of negative rainfall anomalies in the region, and suggest a connection with climatic systems of lower latitudes.

1.1. Study area

The Puyuhuapi fjord is located in northern Patagonia (XI region), in Chile's southern fjord area (~44°50′S). Its basin has a NE–SW orientation (Fig. 1a) and water depths that vary from 50 m at the head of the fjord to 300 m in the center section (Araya, 1997). The Ventisquero Sound is part of the northernmost end of the Puyuhuapi fjord, where the Galvarino Pass divides and connects the northern and southern sections of the sound (Fig. 1b). The Galvarino Pass represents a coastline constriction, decreasing the width of the sound from about 2000 m to nearly 200 m, and changing the depth from 40 m on the northern side to 8 m in the shallowest section of the sill, and to 80 m south of the pass (Valle-Levinson et al., 2001). Freshwater into the Puyuhuapi fjord is mainly supplied by the Cisnes River (~182 $m^3 s^{-1}$), located in the middle section of the fjord and next to Puerto Cisnes. Freshwater to the Ventisquero Sound is mainly provided by the Ventisquero (~34 $m^3 s^{-1}$) and Pascua (no data available) rivers, both of them discharging in the northern side of the sill. The climate of the area is generally characterized by high precipitation (~3000 mm yr^{-1}) (DGA, 2003). High primary production has been measured in the water column (average in spring ~0.3 g C $m^{-2} d^{-1}$; Astoreca et al., 2002). Surface sediments have been characterized as fine (silty-clay) and organic-rich, with values up to 3.8% of organic carbon (C_{org}) and 0.4% of organic nitrogen in some areas (Silva et al., 1998). Water column anoxia has not been reported for the fjord area, although measurements of dissolved oxygen in the water column have never included waters near the sediment–water interface (within ~1 m). Nonetheless, oxygen concentrations as low as 1.5 mL L^{-1} have been detected at about 10 m above the sediments at the head of the Puyuhuapi fjord (Silva et al., 1997).

2. Materials and methods

2.1. Sampling

Sediment samples were obtained from the Puyuhuapi fjord (~44°49′S, 72°56′W) (Fig. 1a, b). Two box-cores were recovered during the Cimar-7 Fiordo expedition (November 2001) aboard AGOR Vidal Gormaz: Station

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