Progress in Oceanography 129 (2014) 1–7

Contents lists available at ScienceDirect

Progress in Oceanography

journal homepage: www.elsevier.com/locate/pocean

Preface

Oceanographic Processes in Chilean Fjords of Patagonia: From small to large-scale studies

Introduction

Subantarctic ecosystems, such as the inner shelf of southern Chile (41–55°S), are characterized by a complex system of fjords, channels, gulf, estuaries, bays, and are affected by physical regimes that may strongly modulate biological productivity. Rhythms and rates of primary production in these highly fluctuating fjord environments depend to a large extent on the timing and magnitude of nutrient supply and light availability for primary producers. In such complex fjord systems, the interaction between oceanic waters and freshwater from multiple sources (e.g., rivers, surface and groundwater runoff, snow/glacier melting, and precipitation) produces strong vertical and horizontal gradients in salinity, density, organic and inorganic nutrient ratios and light availability (Pickard, 1971; Dávila et al., 2002; Silva and Palma 2006; Jacob et al., 2014). The vertical structure of the water column (stratified/mixed), modulated by the seasonal and inter-annual changes of the pycnocline may affect biomass and composition of pelagic and benthic assemblages, and ultimately spatial and temporal patterns of carbon fluxes (the "Biological Pump"), and biogeochemical balances in this large region. In addition, the region is particularly vulnerable to climate change and anthropogenic influences (Iriarte et al., 2010). Remote and large-scale climatic-oceanographic phenomena (e.g., ENSO and Southern Annular Mode) and global climate trends may alter freshwater discharge of large rivers such as the Puelo and Palena, as has also been suggested for the Baker River located between Patagonian Ice fields and other northern fjords shown by paleo-oceanographic (Sepúlveda et al., 2009; Rebolledo et al., 2011) and dendrochronological studies (Lara et al., 2008). Although changes in climate are expected to alter the regional atmospheric forcing such as the West Wind Drift (Quintana and Aceituno, 2012; Garreaud et al., 2013) and the local ocean circulation in this region, including the northward expansion of the subantarctic water, the impact of these changes on physical dynamics, biogeochemical and plankton properties are still unclear. The information presented in this Special Issue (SI) will be important to the understanding and modeling of future changes in the marine carbon cycle in Subantarctic zones off Patagonia.

Main features of the coastal marine ecosystem

The southern region of Chile contains one of the major fjord regions of the world where salty waters of the Subantarctic Surface Water and Modified Subantarctic Waters mix with freshwater from the fjords generating sharp vertical and horizontal salinity gradients (Fig. 1) (Dávila et al., 2002; Acha et al., 2004; Valle-Levinson et al., 2007; Pérez-Santos et al., 2014; Schneider et al., 2014). Consequences of freshwater input are (1) a sizable supply of terrigenous material from large rivers (600–800 $m^3\ s^{-1}$), ice melt and rainfall (2000–7000 mm y^{-1}; e.g., colored Dissolved Organic Matter, González et al., 2013; Lafon et al., 2014), particulate organic matter (Sepúlveda et al., 2011), (2) a cold and freshwater layer overlying a salty-warm water layer that would favor small-scale double-diffusive layering processes, quantified for the first time in Chilean Patagonian fjords (Pérez-Santos et al., 2014), and (3) sharp latitudinal and longitudinal gradients of silicic acid due to surface water mixing between nitrate-rich but Si-depleted oceanic subantarctic waters and Si-rich but nitrate depleted continental waters (Aracena et al., 2011; González et al., 2011; Torres et al., 2014).

Biological consequences of these water column processes are evident: the stratifying effect of buoyancy is a key regulator of primary production and biomass, limiting the depth of turbulent mixing and thereby keeping algal cells within the photic zone (Jacob et al., 2014). On the other hand, stratification isolates algae from their principal source of nutrients below the pycnocline and thus may lead to the eventual shutdown of production after short bloom periods. Here, semidiurnal internal waves can increase vertical mixing of deep nutrients toward the surface, through shear instabilities, which would favor primary production for more extended periods than in classical seasonal systems (Ross et al., 2014). In addition, Valle-Levinson et al. (2014) demonstrated the existence (related to twilight) of semi-diel patterns of vertical migrations of euphausiids and decapods, which could be a common strategy in fjords. Furthermore, some of the Patagonian fjords receive significantly higher loads of fine suspended sediments from snow and glacier melt, which may limit the light available for photosynthesis in near-surface waters, and may explain the low biological production found in these fjords (Jacob et al., 2014). Distributions of harmful algal blooms (HABs, such as *Chaetoceros convolutus*, *Alexandrium catenella*), known for their significant impact on aquaculture and human health and environmental issues, represent major research challenges in coastal waters of the entire Patagonia marine ecosystem. The approaches used by Paredes et al. (2014) allow us to conclude the importance of extrinsic environmental factors (nitrate, temperature) to explain the regional spatial scale of microphytoplankton groups, while toxic dinoflagellate species dynamics may be related to changes in the

http://dx.doi.org/10.1016/j.pocean.2014.10.004

composition of microphytoplankton community at smaller spatial scales.

Vertical migration, feeding, and reproduction of pelagic fish and zooplanktonic populations are also affected to the point that their spatial distribution results from the interaction of fresh and oceanic waters, mainly through the semi-permanent pycnocline observed in fjords and channels. The effect of river outflow was clearly demonstrated by Meerhoff et al. (2014) who pointed out that early and late-stage barnacle larvae were more abundant in waters of low temperature, high oxygen and high chlorophyll, while bivalve larvae were associated with warmer waters of oceanic origin. Population properties such as the ontogenic feeding pattern and distributions of fishes *Sprattus fuegensis* and *Strangomera bentincki*, appeared to benefit from taking advantage of short-term food pulses and thus overcoming changes in oceanographic conditions in fjords (Contreras et al., 2014).

Biogeochemical processes

Muñoz et al. (2014) and Zapata-Hernández et al. (2014) studied a newly discovered shallow cold seep site with bacterial sulfur mats in a Chilean Fjord. Cold seeps have been studied in many regions of the world, but as the authors point out, this is novel for Patagonian fjords. Stable isotope geochemistry of carbon, nitrogen and water, as well as vent fluid geochemistry helped establish that the cold seeps represent a site of chemosynthetic activity that sustain bacterial sulfur mats and are the source of methane in the water column (Muñoz et al., 2014). In the community associated with the cold seeps, the food web is maintained mainly by photosynthetic primary production, and bacterial filaments of the mat may be incorporated into the diet of some grazers (Zapata-Hernández et al., 2014). These studies characterize the chemical composition of reduced compounds in the vent fluids emanating from the rocks that might help understand the presence of bacterial mats nearby, and the functioning of shallow water reducing systems.

Vertical mixing and the exchange of nutrients among the low-salinity, low nutrient and turbid surface layer and the warmer

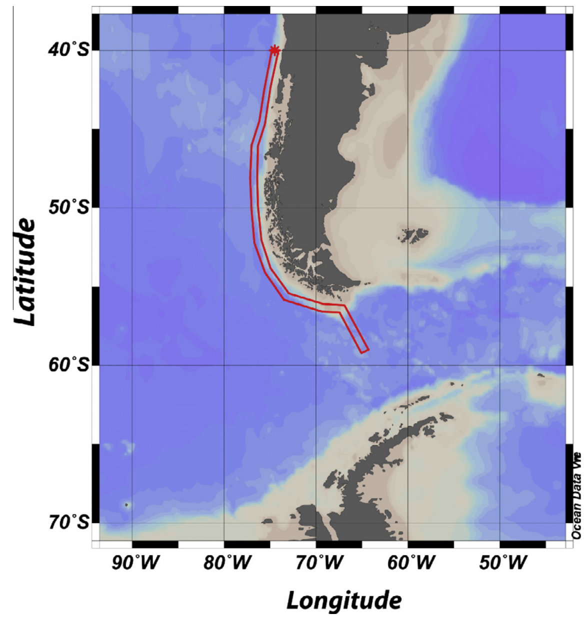

Fig. 2. Map showing the oceanic section from 40°S to 60°S off the Patagonia marine system (from World Ocean Database 2013).

and more saline subsurface layer are the main drivers of spring pulses in primary production and autotrophic biomass in the inner seas of Patagonia (González et al., 2013). The concentrations of inorganic nutrients show a strong seasonal signal, with high nitrate and orthophosphate concentrations during winter, and lower values during spring, presumably caused by a sharp increase in primary productivity when light availability in near-surface waters increases (Iriarte et al., 2007; González et al., 2011; Torres et al., 2011; Jacob et al., 2014). Oxygen concentrations in the fjords is mostly the result of horizontal advection of adjacent well-oxygenated Subantarctic Waters (5–6 mL L^{-1}) that represents the major source of oxygen in the deep layers of the inner seas of Patagonia

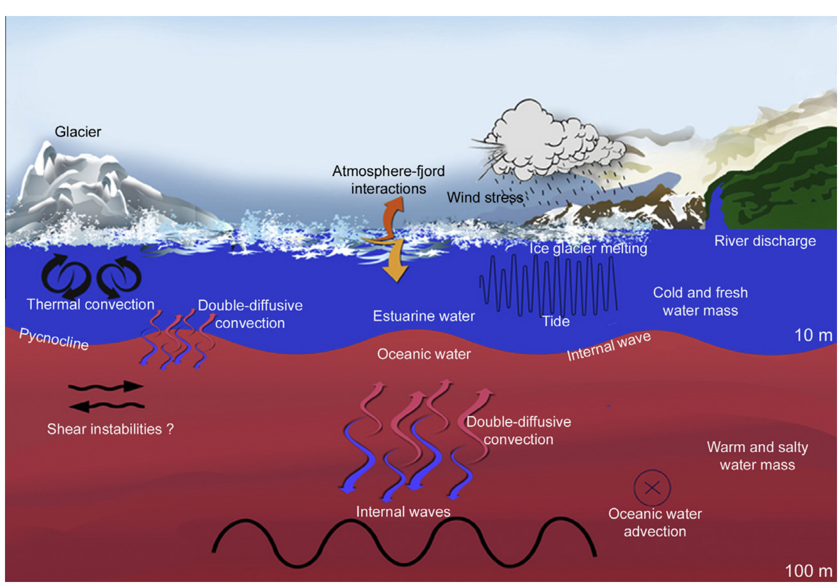

Fig. 1. Schematics of important coastal processes considered in this compilation of articles showing geomorphology (glaciers), physical forcing (wind stress, atmosphere–ocean temperature exchange) and distributions of waters of different temperature and salinity in Patagonian fjords. Permanent surface freshwater plumes from the rivers' watershed, and ice melt from glaciers, on top of warm and salty oceanic waters promote a sharp near surface stratification (halocline and pycnocline) of the water column. Nutrient enrichment of the near surface waters (photic layer) may occur through tidal fronts, tidally induced internal waves, shear instabilities and small scale processes such as double diffusive convection. (Figure credits, Dr. Ivan Peréz-Santos).