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Zooplankton structure and vertical migration: Using acoustics and biomass to compare stratified and mixed fjord systems

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A B S T R A C T

The patterns of abundance, composition, biomass and vertical migration of zooplankton in short-time scales (< 41 h) were described in two sites representative of stratified (Reloncaví Fjord) and mixed (Ancud Gulf) water columns during austral winter season in Chilean northern Patagonia. Vertical profiles of a 75 kHz ADCP device mounted on the hull of a ship were used to obtain vertical profiles of current velocity data and intensity of the backscattered acoustic signal, which was used to study the migratory strategies and to relate the echo intensity with zooplankton biomass. Repeated vertical profiles of temperature, salinity and density were obtained with a CTD instrument to describe the density patterns during both experiments. Zooplankton were sampled every 3 h using a Bongo net to determine abundance, composition and biomass. Migrations were diel in the stratified station, semi-diel in the mixed station, and controlled by light in both locations, with large and significant differences in zooplankton abundance and biomass between day and night samples. No migration pattern associated with the effect of tides was found. The depth of maximum backscatter strength showed differences of approximately 30 m between stations and was deeper in the mixed station. The relation between mean volume backscattering strength (dB) computed from echo intensity and $\log_{10}$ of total dry weight (mg m^{-3}) of zooplankton biomass was moderate but significant in both locations. Biomass estimated from biological samples was higher in the mixed station and determined by euphausiids. Copepods were the most abundant group in both stations. Acoustic methods were a useful technique to understand the detailed patterns of migratory strategies of zooplankton and to help estimate zooplankton biomass and abundance in the inner waters of southern Chile.

1. Introduction

Thermal stratification and mixing are key processes in the development of primary production in temperate coastal seas. Phytoplankton growth is highly dependent on the changes in vertical density of the water column induced by solar radiation in response to the development of stratification in spring and summer. In winter, convective overturning induced by wind and tides generates turbulent motion that maintains vertical homogeneity of the water column, favoring vertical mixing of inorganic nutrients (Lalli and Parsons, 1997). The conditions in estuarine systems may be different, because buoyancy is mostly induced by freshwater inputs from coastal rivers, which may cause whole year stratification in regions close to sources of freshwater. Additionally, the enhanced effect of tidal currents in these shallow systems might promote vertical mixing in some areas most of the year (Iles and Sinclair, 1982). Tidal currents, freshwater inputs, and other external factors also influence the advection and dispersion of organisms, affecting their distribution in the water column (Nielsen and Andersen, 2002; Castro et al., 2011; Landaeta et al., 2015). The interaction of these factors with bottom topography and coastal geometry at a variety of spatial and temporal scales may lead to the formation of areas of mixing and stratification in estuarine systems.

The effect of stratification and mixing processes on higher trophic levels has received attention in terms of distribution, abundance, composition and biomass of zooplankton populations. In temperate waters, vernal stratification is usually a structuring factor of zooplankton populations (Norrbin et al., 1996), with distributions affected by more by tidal and density fronts (Wiebe et al., 1996; Wishner et al., 2006) than by food availability (Norrbin et al., 1996). Abundance and biomass are usually lower in well-mixed than in stratified locations (Wiebe et al., 1996; Wishner et al., 2006), because the delay in the warming of the water column results in slow growth of zooplankton populations, which do not peak until mid-summer (Fransz and Gieskes, 1984). Wishner et al. (2006) identified this pattern for the three most

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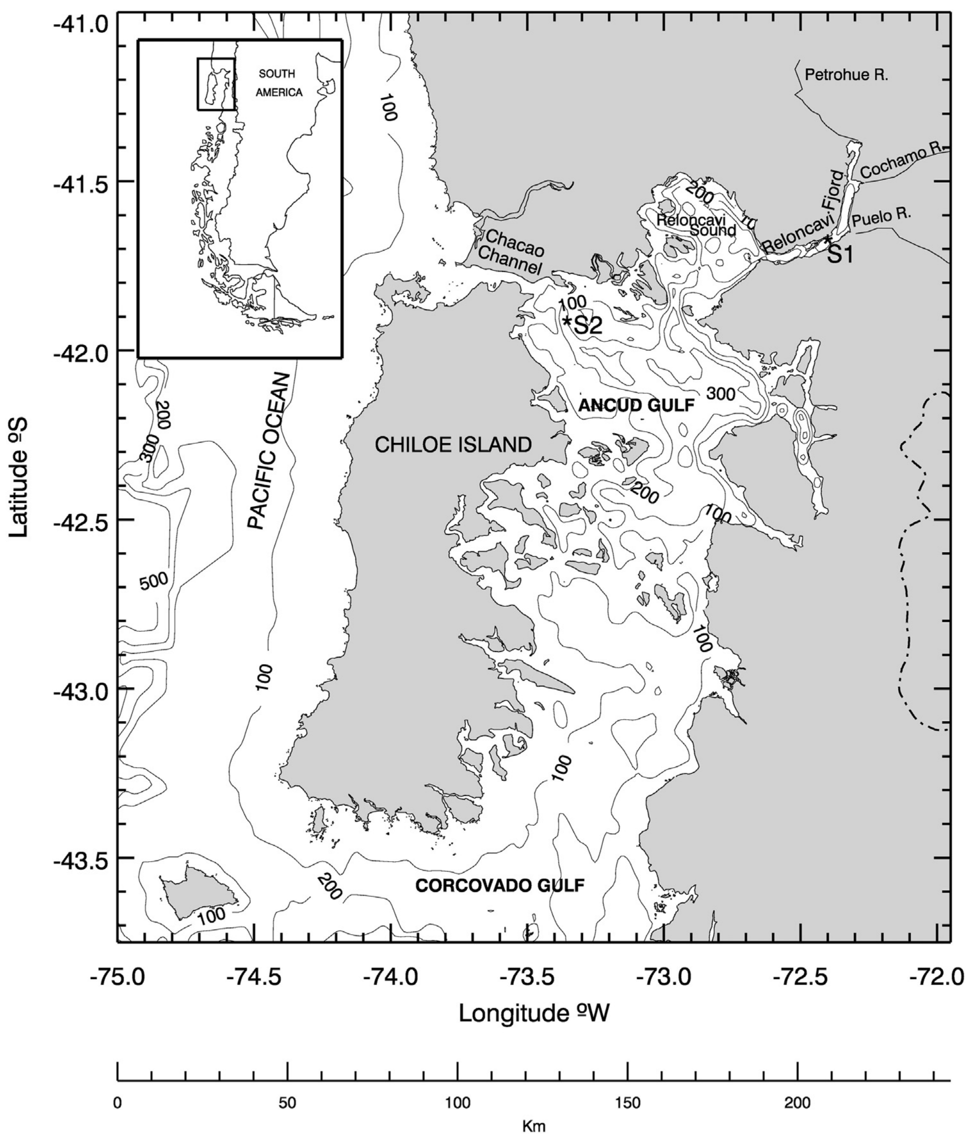

Fig. 1. Area of study where S1 is the location of station 1 in Reloncaví Fjord, and S2 is station 2 in Ancud Gulf. Isobaths of 100, 200, 300, 400 and 500 are drawn for reference about bathymetry of the area. Dash dotted line is international boundary.

abundant taxa of Georges Bank (copepods, pteropods and echinoderm larvae) but not for the larvae of benthic organisms (except echinoderms), which were more abundant in the mixed station. In European shelf seas, tidally mixed waters are dominated by smaller copepods; whereas thermally stratified waters are apparently dominated by larger calanoid copepods (Williams et al., 1994).

Stratification and mixing processes also affect the vertical distributions of organisms, including migration patterns. For example, during mixed conditions, organisms are distributed deeper and weaker migrations may occur (Lagadeuc et al., 1997; Rawlinson et al., 2004). In terms of vertical distribution, diel vertical migration (DVM) is the most common type of zooplankton movement, which is the ascent of organisms to the surface layers near sunset and the descent to deep layers around sunrise. This type of migration occurs in at least one species of all major groups of zooplankton, in both freshwater and saltwater systems (Hays, 2003). In terms of biomass, DVM of zooplankton is the largest daily migration in the animal kingdom (Hays, 2003; Bozzano et al., 2013; Van Haren and Compton, 2013). This phenomenon explains the differences found in biomass, abundance and species composition of zooplankton between day and night (Lalli and Parsons, 1997; Pinot and Jansá, 2001) in the surface layers.

Vertical migrations have been attributed to light intensity (Cohen and Forward, 2009), predation (Pearre, 2003; Ramos-Jiliberto et al., 2004), food availability (Huntley and Brooks, 1982; Dagg, 1985), and temperature (Williamson et al., 2011). For example, Holliday et al. (2010) identified nighttime layers of zooplankton associated with layers of phytoplankton at the zone of maxima subsurface chlorophyll in summer, demonstrating that this zone had relatively high concentrations of food for grazing zooplankton. However, DVM is a facultative pattern that can be altered under several conditions. For example, migrations can be associated with the effect of semidiurnal tidal currents, as proposed by Queiroga et al. (1997) for some decapod larvae, and by Hill (1998) detected a strategy of organisms to use tidal stream transport. Notably, in a previous study using the backscatter signal from a long-time series of ADCP data (> 4 months) in Reloncaví Fjord (one of the study sites of this work), Valle-Levinson et al. (2014) observed a semi-diel migration, consisting of two double excursions linked to light levels.

In recent decades, the use of acoustic profilers has supplemented studies of zooplankton biomass and abundance (Flagg and Smith, 1989; Cisewski et al., 2010). DVM produces dense sound-reflecting aggregations called deep scattering layers (DSL) that are detected by acoustic profilers by bouncing the sound beams (Lalli and Parsons, 1997), with the returning acoustic signal, or backscatter, an estimation of zooplankton abundance (Salas de León et al., 2005). Acoustic profilers have been widely used to document diel vertical migration (Heywood,