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Vertical distribution, composition and migratory patterns of acoustic scattering layers in the Canary Islands

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ABSTRACT

Diel vertical migration (DVM) facilitates biogeochemical exchanges between shallow waters and the deep ocean. An effective way of monitoring the migrant biota is by acoustic observations although the interpretation of the scattering layers poses challenges. Here we combine results from acoustic observations at 18 and 38 kHz with limited net sampling in order to unveil the origin of acoustic phenomena around the Canary Islands, subtropical northeast Atlantic Ocean. Trawling data revealed a high diversity of fishes, decapods and cephalopods (152 species), although few dominant species likely were responsible for most of the sound scattering in the region. We identified four different acoustic scattering layers in the mesopelagic realm: (1) at 400–500 m depth, a swimbladder resonance phenomenon at 18 kHz produced by gas-bearing migrant fish such as *Vinciguerria* spp. and *Lobianchia dofleini*, (2) at 500–600 m depth, a dense 38 kHz layer resulting primarily from the gas-bearing and non-migrant fish *Cyclothone braueri*, and to a lesser extent, from fluid-like migrant fauna also inhabiting these depths, (3) between 600 and 800 m depth, a weak signal at both 18 and 38 kHz ascribed either to migrant fish or decapods, and (4) below 800 m depth, a weak non-migrant layer at 18 kHz which was not sampled. All the dielly migrating layers reached the epipelagic zone at night, with the shorter-range migrations moving at 4.6 ± 2.6 cm s^{-1} and the long-range ones at 11.5 ± 3.8 cm s^{-1}. This work reduces uncertainties interpreting standard frequencies in mesopelagic studies, while enhances the potential of acoustics for future research and monitoring of the deep pelagic fauna in the Canary Islands.

1. Introduction

Acoustic scattering from marine organisms is caused by body structures with densities notably different from water, such as gas bladders or lipid inclusions (Aguilar et al., 2008). Thanks to this phenomenon, the vertical distribution of pelagic animals can be easily monitored using scientific echosounders (Kloser et al., 2002; Kaartvedt et al., 2009; Cade & Benoit-Bird, 2015). Two reflecting regions are normally visible in the ocean, the shallow and the deep scattering layer (SSL and DSL) occurring respectively in the epipelagic and the mesopelagic domains (0–200 and 200–1000 m depth), with the latter often portioned into multiple layers. Part of the biota forming the DSLs feed between dusk and dawn in the epipelagic zone, producing a thicker and more intense SSL during the night. This displacement is known as diel vertical migration (DVM), occurring on a daily basis around the world's oceans and performed by a large variety of zooplankton and micronekton species (Tucker, 1951; Barham, 1966; Roe, 1974; Pearre, 2003).

DVM promotes trophic interactions and biogeochemical exchanges between the upper layers and the deep ocean (Ducklow et al., 2001; Robinson et al., 2010), and its study is therefore important for understanding pelagic ecosystems functioning. The micronekton component, mainly fishes, decapods and cephalopods between 2 and 10 cm in length (Brodeur et al., 2005), is expected to account for a substantial export of carbon to the deep ocean as they comprise a significant fraction of the migrant biomass (Angel & Pugh, 2000), and cover more extensive depth ranges than zooplankton (Badcock & Merrett, 1976; Roe, 1984b; Domanski, 1984). In fact, the importance of fishes and decapods in mediating carbon export has been recently highlighted by several studies (Hidaka et al., 2001; Davison et al., 2013; Schukat et al., 2013; Hudson et al., 2014; Ariza et al., 2015). Therefore, using acoustic observations

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for monitoring their distribution and migrations may be a powerful tool for the ocean carbon pump assessment.

The present study focus on micronekton from mesopelagic waters nearby the Canary Islands, a region in the subtropical northeast Atlantic exhibiting open-ocean and olygotrophic gyre characteristics (Barton et al., 1998; Davenport et al., 2002; Neuer et al., 2007). Due to its position between temperate and tropical waters, this faunal province presents a high diversity of mesopelagic micronekton in comparison to other latitudes (Backus & Craddock, 1977; Badcock & Merrett, 1977; Landeira & Fransen, 2012). In the Canary Islands, the vertical distribution of fishes (Badcock, 1970), decapods (Foxton, 1970a; Foxton, 1970b), cephalopods (Clarke, 1969) and euphausiids (Baker, 1970) was thoroughly studied in the SOND cruise during the mid-sixties (Foxton, 1969), providing valuable knowledge about DVM in the area. More recent studies have contributed to a more detailed catalogue of mesopelagic micronekton illustrating community differences between neritic and oceanic realms around the Canary Islands (Bordes et al., 2009; Wienerroither et al., 2009). However, the lack of integrated studies combining acoustic data and biological information from net sampling has prevented the identification of the specific organisms responsible for each scattering layer occurring in the archipelago. Acoustic properties of midwater fauna may help in this task. For instance, the swimbladder of fishes produce resonance under certain frequencies and pressure conditions, depending on its size and internal structure (Andreeva, 1964; Capen, 1967; Weston, 1967; Kloser et al., 2002). Thus, the swimbladder features of dominant mesopelagic fishes can be used in combination with resonance models to investigate the origin of acoustic scattering.

This study describes the acoustic properties and the vertical distribution of scattering layers at 18 and 38 kHz occurring from the surface to 1000 m depth in the Canary Islands, as well as their diel migrant movements between the epipelagic and the mesopelagic zone. We also present the first attempt to identify organisms causing these layers by trawling. The assessment of species composition of the scattering biota was complemented with a swimbladder resonance model, and also contrasted with previous reports of the micronekton vertical distribution in the region.

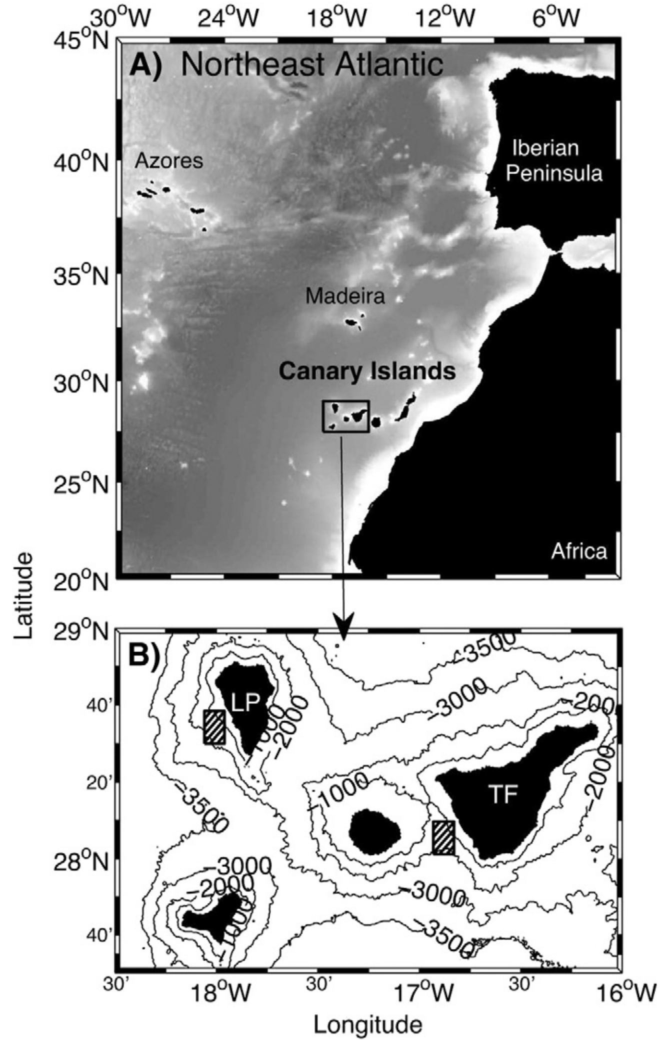

Fig. 1. (A) Map showing the situation of the Canary Islands west off Africa. (B) Study areas southwest of La Palma and Tenerife Islands where acoustic recordings and net trawling were conducted (striped rectangles).

2. Methods

2.1. Survey

The survey was conducted in two locations southwest of La Palma and Tenerife Islands (Canary Islands), between the 1000 and 2000 m isobaths (Fig. 1). From the 9 th to the 18 th of April 2012, hydrographic and acoustic data, as well as micronekton samples were collected on board the R/V *Cornide de Saavedra*.

2.2. Hydrography

Vertical profiles of conductivity and temperature were collected using a SeaBird 9/11-plus CTD equipped with dual conductivity and temperature sensors. CTD sensors were calibrated at the SeaBird laboratory before the cruise. A sensor for measurements of dissolved oxygen (SeaBird SBE-43) and fluorometer for chlorophyll *a* estimations (WetLabs ECO-FL) were linked to the CTD unit. Seawater analyses of dissolved oxygen (Winkler titrations) and chlorophyll *a* extractions were performed to calibrate the voltage readings of both sensors. Analyses were carried out in accordance with the JGOFS recommendations (UNESCO, 1994). Temperature, dissolved oxygen and chlorophyll *a* profiles were averaged from 3 CTD casts performed within each sampling area off La Palma and Tenerife Islands (Fig. 2).

2.3. Acoustics

Hull-mounted SIMRAD EK60 echosounders operating at 18 and 38 kHz (11° and 7° beam width, respectively) were used for recording acoustic data. Configuration was set at 1024 µs pulse duration and one ping every 3 s. Due to the draft of the transducer and to prevent near-field effects (Simmonds & MacLennan, 2005), acoustic data for the first 10 m depth were not available. In order to avoid the range-increasing noise (Korneliussen, 2000), maximum depth of data used was 1000 m, and minimum threshold was set to −80 dB. The echosounders were calibrated *in-situ* by standard techniques (Foote et al., 1987). Since acoustic records covered several days while trawling in each location, we opted for showing a composite echogram per location, which were obtained by averaging the daily acoustic data every minute (Figs. 3 and 4). Fragments with scattering layers visibly affected by steaming noise or interferences from other acoustic devices were removed before averaging. Echograms were shown at 18 kHz and 38 kHz, and also as the difference between both frequencies (18 kHz minus 38 kHz). In order to calculate approximate vertical migration velocities, we manually marked sets of points over different migratory traces observed at 18 and 38 kHz. The velocities were extracted by averaging the slopes along the curves fitted to these points. All acoustic data were processed using customized applications in Matlab software.

2.4. Biological sampling

Micronekton was captured using a pelagic trawl with a 300 m^2 mouth area and 45 m length. The mesh size was 80 cm near the opening,