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Oceanographic influences on Deep Scattering Layers across the North Atlantic

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ABSTRACT

The distribution and density of Deep Scattering Layers (DSLs) were quantified along North Atlantic transits from Ireland to the Grand Banks of Newfoundland in the springs of 2012, 2013 and 2014 employing a calibrated Simrad EK60 echo sounder at 38 kHz. Concurrently, Sippican T5 XBTs (eXpendable Bathy Thermographs) were used to profile temperatures to 1800 m. In each year the scattering layers spanned the deep basin at depths ranging from near surface to approximately 900 m, but annual mean densities differed significantly. Higher DSL densities were recorded during years that exhibited higher sea temperatures at the depths of major DSL concentration (400–600 m), higher sea level anomalies and stronger eastward geostrophic currents. The highest concentration of the DSLs in each year was found in the area east of the Grand Banks that corresponded with areas of anticyclonic eddies. In this region DSL densities in 2014 were among the highest recorded worldwide (>7000 m^2 nautical mile^{-2}). Midwater fishing indicated DSLs were dominated by Myctophids and Sternoptychids. Anticyclonic eddy formation is discussed as a possible means of transport and aggregation of the DSLs in that region, where oceanographic influences may play a dominant role in the distribution and density of the DSLs and upper trophic level fishes.

1. Introduction

Deep Scattering Layers (DSLs) were first noted in records of high frequency sonars during WWII, as a layer of enhanced acoustical backscatter, and since those early observations DSLs have been found throughout deep sea regions of the world ocean (Irigoien et al., 2014). Initial observations revealed that the depths and compositions of scattering layers varied; a trans-pacific scattering layer was found as shallow as 60 m (Barraclo et al., 1969), whereas a DSL at 1700 m was found off the Californian coast (Johnson, 1973). In composition, DSLs are typically comprised of mesopelagic fishes (Myctophids and many other species are present in varying proportions) and planktonic crustaceans. These layers, or some component of them, may migrate vertically with light cycles (Orlowski, 1990; Kloser et al., 2009). In contrast, non-migratory DSLs have been found entrained in warm core eddies around the Gulf Stream, these DSL's displayed little vertical response to light, pressure or temperature but rather responded more to oceanographic influences of the structure itself (Conte et al., 1986).

Former global estimates of the DSL based on trawling suggested a figure of 1,000 million tons, but more spatially comprehensive acoustic measures suggest a biomass many times higher and that they may be the most abundant fishes in the biosphere (Irigoien et al., 2014). The potential importance of this biomass in carbon cycling and marine food webs has recently been postulated (Irigoien et al., 2014). Following earlier studies in parts of the North Atlantic (Orlowski, 1990; Magusson, 1996 and references therein), recent research has used modern scientific multi-frequency echo sounders to observe fine-scale structures in the DSLs in other regions of this ocean (Godo et al., 2009, 2012). Nonetheless, little research has been carried out with regards to the spatial and temporal variation of the DSLs across the North Atlantic, or their distribution in the dynamic oceanographic region between 35 and 45 W in the northwest Atlantic.

The Gulf Stream and its branches are dominant oceanographic features in the North Atlantic. The Gulf Stream initially tracks north along the western boundary of the Atlantic, is deflected

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eastward south of the Grand Banks to approximately 50 W whereupon it breaks into a number of eastward and northeastward flowing currents often referred to as the North Atlantic Current or Drift (Krauss, 1986;Mann, 1967). From its origins onward, the proximity of the Stream to land and other counterflowing currents and bathymetry causes meandering and instabilities that often develop into eddies. In particular, the highly unstable currents in the northwest Atlantic eastward of the Grand Banks result in characteristically high amplitude eddies (Chelton et al., 2011), these changes in amplitudes or sea level height can be seen in altimeter data. Most mesoscale eddies found throughout the world propagate westward, however Gulf Stream eddies also move eastward as they do in the Antarctic Circumpolar Current (Chelton et al., 2011). Eddies transport heat, water and small entrained organisms (Chelton et al., 2011; Mittelstaedt, 1987; Samuelsen et al., 2012) and have been found to penetrate down to 2500 m (Mittelstaedt, 1987), deeper than the distribution of any known DSL. Eddies have been described as ‘oases in the desert’ (Godo et al., 2012), wherein the vertical, horizontal and rotational nature of anticyclonic and cyclonic eddies concentrates plankton and fish larvae (Nakata et al., 2000). Recent studies in the northeastern Atlantic observed concentrations of the DSL around the edges of eddies (Godo et al., 2012). We postulated that the stronger eddies of the northwestern Atlantic would concentrate and potentially move DSL entrained organisms northward along the outer edges of the Grand Banks and hence become “buses” rather than fixed “oases” of concentrated organisms which may attract higher trophic level fishes.

Our objectives in this paper were twofold: first, to quantify the distribution and density of the DSLs across the North Atlantic, from the Irish continental Shelf to the Grand Banks of Newfoundland in multiple years, and second, to investigate the hypothesis that the presence of anticyclonic eddy formation in the northwest Atlantic would lead to elevations and concentrations of DSL biomass in that region around eddy “hotspots” and in turn that they could act as transport “buses” of DSL organisms.

2. Methods

Transits across the North Atlantic were made on the RV *Celtic Explorer* (65 m) in the springtime of 2012–2014 (30th April-5th May 2012; 16th–26th April 2013; 12th–25th April 2014) as shown in Fig.1. The RV *Celtic Explorer* is ultra-quiet and exceeds ICES 209 (Mitson, 1985) standards for underwater noise limits of fisheries research vessels at 10 knots (nominal survey speed).

Sea conditions were calm (wave heights <1 m) for the majority of all transits. Vessel speed was an average of 8 knots due in most cases to the eastward flowing currents. During the transits, a Simrad EK60 scientific echo sounder was operated continuously with 200, 120, 38 and 18 kHz transducers mounted on a “drop” keel that extended 8.8 m below the sea surface. In this paper, only the 38 kHz data were used to describe the full distribution and density of the DSLs, as signal to noise ratios for the higher frequencies limited their use below a few hundred metres, and the 18 kHz signal may be subject to resonance and was only used to track the seafloor (Godo et al., 2009). In addition, most recent research on DSLs has utilized 38 kHz EK60 echosounders, which makes comparisons straightforward. Calibration was carried out (Table 1) according to standard procedures just prior to each transit (Foote et al., 1987).

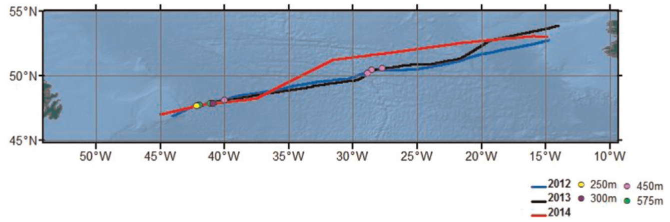

Fig. 1. Cruise tracks of the RV Celtic Explorer for 2012, 2013 and 2014 overlain with the depths (m) of fishing sets during the cruises of 2013 and 2014.

Table 1
Setup and calibration measures for the 38 kHz transducers of the Kongsberg Simrad (Horton, Norway) EK60 split-beam echosounder. These settings are from the March 2014 calibration. They differ only slightly and not significantly from settings in calibrations in March of 2012 and 2013 (e.g., gains <0.1 dB).

	38 kHz (Simrad ES38B)
Power	2000 W
Pulse duration	1.024 ms
Calibration range	16–20 m
Gain	25.98 dB
Athwart beam angle: offset	7.00; −0.03 degrees
Alongship beam angle; offset	6.93; −0.06 degrees
Sa correction	−0.69 dB

Acoustic data were displayed and edited in Echoview 6 software (Myriax, Hobart, Australia). Data from 0 to 10 m from the transducer face were excised to account for full beam formation and restrict any surface interference, thus limiting ensonification to beyond 18.8 m from the sea surface. The 38 kHz signal was analyzed from the surface limit to 1000 m; as attenuation reduced signal to noise ratios to below acceptable limits at greater depths. Nonetheless, on the 38 kHz recordings there appeared to be very limited signal easily attributable to biological origin at greater depths. Acoustic returns (38 kHz) within the analyzed range were manually edited for infrequent noise spikes then integrated at a signal threshold of −75 dB within 1 nmile horizontal by 50 m vertical bins. Graphic displays used Surfer and Grapher software (Golden Software, Colorado, USA). No conversions from backscatter to biomass were made as a consequence of uncertainties about acoustic target strength (e.g. Irigoien et al., 2014). Nonetheless, backscatter reported as Nautical Area Scattering Coefficients (m^2 nautical mile^{-2}) provides a comparable index of biomass among surveys and studies. We recognize that vertically migrating fishes with swim-bladders may exhibit diel changes in backscatter that could bias comparisons both within and among studies, but this aspect is beyond the scope of the present paper.

A total of 8 fishing sets (4 in 2013 and 4 in 2014) were carried out during daylight hours using a Grande Ouverture Verticale (GOV) trawl with small mesh liner (Reid et al., O'Neill) fished pelagically at 3.5 knots within the DSL at several depths and locations (Fig. 1). This sampling method was not ideal but provided some data on the composition of the layers with which to compare to published studies using more efficient netting gear but lacking the spatial or temporal coverage of the present study (e.g., Godo et al., 2012).

Oceanographic data were collected using Sippican XBT T5 probes (eXpendable Bathy Thermographs). The XBTs were deployed every 30 nautical miles down to a depth of 1800 m and every 15 nautical miles through areas where large altimeter changes were noted in near real time data accessed online through CCAR (Colorado Centre for Astrodynamics Research) or where significant changes in temperature or echosounder recordings were observed during the survey. XBT data were processed using the Sippican Mk21 software, quality controlled in Microsoft Excel and sections produced through Matlab R2008a (Massachusetts, USA). Average sea temperatures for each entire transect were calculated for a depth of 400–600 m (Table 3). Winter mixed layer depths were calculated using the largest vertical gradient between