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ScienceDirect
Deep-Sea Research II 55 (2008) 254–268
DEEP-SEA RESEARCH PART II
www.elsevier.com/locate/dsr2

Small-scale spatial variability of sperm and sei whales in relation to oceanographic and topographic features along the Mid-Atlantic Ridge

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Accepted 17 September 2007

Abstract

The 2004 Mid-Atlantic Ridge (MAR)-ECO expedition on the R.V. *G.O. Sars* provided the first opportunity to correlate oceanic distributions of cetaceans with synoptic acoustic (ADCP to 700 m depth, multi-beam echosounders) measurements of high-resolution, three-dimensional (3D) potential habitat (spatial scale < 100 km). The identified habitat features were tested with independent observations from the Icelandic combined cetacean and redfish cruises in 2001 and 2003 using data from a 3D ocean general circulation model of the MAR region (Regional Oceans Modelling System (ROMS) model 5 km resolution). The spatial autocorrelation of sampled encounter rates of sperm *Physeter macrocephalus* and sei whales *Balaenoptera borealis* indicated scale-dependent variability in the distribution of both species. Despite the large area surveyed, the observations of both species exhibited a strong small-scale structure (range parameter 20–50 km), indicating affinities to cross-seamount or cross-frontal structures. Potential cross-seamount and cross-frontal habitat structures were derived from the acoustic transect data by analysing fine-scale gradients in the 3D flow patterns and bathymetry, including interactions between frontal and topographic parameters. PLS regression was used to determine the potential habitat drivers of sperm and sei whales, both during the *G.O. Sars* cruise and during the Icelandic cruises in 2001 and 2003. The selected parameters, which reflected flow gradients interacting with the steep topography, were finally applied for modelling the habitat suitability of both target species along the northern MAR using Ecological Niche Factor Analysis. The results suggest aggregations of sperm and sei whales along the MAR are primarily associated with fine-scale frontal processes interacting with the topography in the upper 100 m of the water column just north of the Sub-Polar Front (SPF) and the Charlie–Gibbs Fracture Zone (CGFZ). As moderate and high habitat suitabilities were estimated only for areas downstream from the SPF, the findings suggest that the animals capitalise on secondary production maintained by enhanced primary production associated with the frontal processes in the upper part of the water column in the CGFZ and at the Faraday Seamounts. Further studies are encouraged to evaluate the importance of the bio-physical coupling, and the significance of small-scale frontal processes in the surface and subsurface waters north of the SPF for the transfer of energy to higher trophic levels in the North Atlantic.

Keywords: Cetaceans; Oceanic fronts; Mid-Atlantic Ridge; Spatial structure; Bio-physical coupling; Habitat modelling

1. Introduction

Cetaceans inhabit the earth's most extensive habitat; open oceans outside continental shelf environments. Systematic surveys of cetaceans have occurred in many slope and deep oceanic regions, with the intent to derive abundance estimates for stock management. Limited ecological research has been carried out on cetaceans during assessment surveys or as dedicated projects to examine potential ocean habitats. Potential habitat studies have used topographic variables to correlate abundance of

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doi:10.1016/j.dsr2.2007.09.020

cetaceans with seabed structures at various scales (Baumgartner et al., 2001; Williams et al., 2006; Yen et al., 2004) or surface and three-dimensional hydrodynamic parameters averaged over survey periods (Burtenshaw et al., 2004; Panigada et al., 2006). Reduced effort has focused on the small-scale variability of cetaceans in relation to oceanographic variables in the open ocean. The *G.O. Sars* leg 1 cruise along the Mid-Atlantic Ridge (MAR) in June 2004 provided a unique opportunity to examine oceanic habitats of cetaceans using synoptic three-dimensional acoustic recordings of the fine-scale structure of the water column and the seabed.

The *G.O. Sars* cruise recorded aggregations of zooplankton and nekton in several parts of the MAR region, most notably at the Sub-Polar Front (SPF) and in the Charlie–Gibbs Fracture Zone (CGFZ) (Opdal et al., 2008; Gaard et al., 2008). Observations of cetaceans revealed concentrations of sperm *Physeter macrocephalus* and sei *Balaenoptera borealis* whales in the same areas. Detailed analyses of the association between observations of sei and sperm whales and the dynamic features of the water column and the seabed topography may assist in the determination of habitat features that are important to cetacean feeding. Aggregations of feeding cetaceans may be associated with the enhanced secondary production frequently reported at and downstream of seamounts (Dower and Brodeur, 2004; Genin, 2004). Sperm whales are essentially piscivorous but also feed on cephalopods, while sei whales are planktivorous (Roe, 1969; Martin and Clarke, 1986; Christensen et al., 1992; Santos et al., 1999). Identification of biological and physical factors associated with high density feeding aggregations of sperm and sei whales may help understand the role of biophysical interacting processes that transfer energy along different pathways to higher trophic levels in open ocean ecosystems such as the MAR. Specifically, knowledge of potential habitat drivers, i.e. type, scale and interaction of key factors, for whales along the MAR may assist in the assessment of the role of different processes (meso-scale processes of the SPF/smaller scale processes at seamounts downstream from the SPF) in the development of enhanced secondary production recorded in the MAR region.

2. Material and methods

2.1. Physical oceanography of the study area

The area covered in this analysis encompasses the northern MAR from 37° to 61° N and from 19° to 38°W (Fig. 1). The Icelandic cruises used to evaluate the identified factors that influence marine mammal habitat drivers and subsequent habitat predictions included the northern MAR and parts of the eastern Irminger Sea from 53° to 63° N and from 19° to 40°W. The topography of the area is dominated by the MAR, which is located centrally with depths varying between approximately 500 and 2000 m. Both within the MAR and on the slopes towards the Irminger and Iceland Basins steep gradients occur. The dominant feature of the MAR is a ridge structure with numerous hills, but only few of the hills classify as seamounts in the normal sense of the term. One cluster of seamounts is found at 48° N; Faraday Seamounts (Fig. 1). North of these seamounts a fracture zone opens the MAR and further north at 52° the CGFZ functions as the major pathway for exchange of water masses between the two basins (Bersch, 1995; Rossby, 1996; Bower et al., 2002).

The circulation along the northern MAR results from subpolar and subtropical gyres, feeding water masses and currents into the study area. Due to marked density differences between the water masses, most of the region has a complex vertical stratification pattern. Sperm and sei whales feed in different layers of the stratified water column. Sperm whales are deep divers while the planktivorous sei whales are shallow divers (Horwood, 1987; Gregr, 2003). Digital tags indicate an effective maximum diving depth of sperm whales during feeding to approximately 985 m (Watwood et al., 2006), while sei whales are believed to feed closer to the surface. Accordingly, acoustic current data from the upper 700 m from the *G.O. Sars* cruise have been included in the analysis of habitat drivers.

2.2. Acoustic measurements of currents and depth

Acoustic backscatter data were collected continuously along the MAR-ECO Leg 1 cruise track (Opdal et al., 2008). Current velocities in the upper 500–700 m of the water column were recorded by a 75 kHz RDI Ocean Surveyor ADCP (Søiland et al., 2008). The ADCP was run in the narrow band mode with 45 vertical bins each 20 m deep and recorded useable data to 500 m depth. Five frequency (18, 38, 70, 120, and 200 kHz) water-column data were collected by a Simrad EK-60 splitbeam echosounder. The RDI software WmDas was used for data acquisition and the CODAS system (http://currents.soest.hawaii.edu) was used for initial post-processing of the data in 300-s averages.

The bottom depth was continuously logged using a Simrad EK 60 split beam echosounder and by a Kongsberg EM300 multibeam sonar. Both systems were synchronised with the ADCP.

2.3. Hydrodynamic and flow modelling data

To describe the small-scale variability in oceanographic parameters throughout the northern MAR we used data from the Regional Oceans Modelling System (ROMS) set up for the MAR region. ROMS is a hydrostatic, 3D, primitive equation, free surface model using stretched, terrain-following coordinates in the vertical and orthogonal curvilinear coordinates in the horizontal (Lien et al., 2006; Shchepetkin and McWilliams, 2005). The North Atlantic ROMS model has a horizontal resolution of 5 km and a vertical resolution of typically 5–10 m in the upper 100 and 100–200 m resolution in the deeper parts of the water column. We imported mean U (eastern component)