Zooplankton distribution in a hypoxic eddy in the Eastern Tropical North Atlantic - an "open ocean dead zone"?

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Summary
The recent discovery of mesoscale eddies in the Eastern Tropical North Atlantic (ETNA) that harbor an intense oxygen minimum zone (OMZ) just below the mixed layer has led us to conduct an interdisciplinary eddy hunt. In spring 2014, an anticyclonic mode water eddy passing north of Cape Verde was tracked using satellite data and gliders, followed by ship-based sampling. The eddy was characterized by increased nitrate and Chl-*a*, along with a 1.5 to 2-fold increase in total area-integrated zooplankton abundance. O_2 concentrations were as low as 4.5 µmol kg^{-1} (85 to 120 m depth). In this depth range, a marked reduction in target strength (shipboard ADCP, 75 kHz) at nighttime was evident. Acoustic scatterers were avoiding this zone and were compressed at the surface. However, vertically stratified multinet hauls and Underwater Vision Profiler (UVP5) image data revealed that this depth range was not completely void of metazoan life. Many of the smaller and/or less mobile organisms targeted by the multinet were able to tolerate conditions in the shallow OMZ. In particular, *Oncaea* spp., ostracods, eucalanoid copepods and siphonophores seemed to favor this zone, while e.g. euphausiids appeared to avoid it.

Introduction
The ETNA features a permanent mesopelagic OMZ at approximately 300-600 m depth, coinciding with the daytime depth of many vertically migrating zooplankton organisms. Oxygen concentrations in this deep OMZ hardly fall below 40 µmol kg^{-1} (Karstensen *et al.* 2015) and obviously do not severely impair the aforementioned organisms. They are, however, sufficiently low to exclude highly active top predators and are thought to decline in the course of climate change (Stramma *et al.* 2008). Submesoscale and mesoscale eddies (with a diameter on the order of 10^1 and 10^2 km, respectively) often represent hotspots of biological productivity in the otherwise oligotrophic open ocean (Godø *et al.* 2012). The recent discovery of mesoscale eddies that harbour extremely low oxygen concentrations just below the mixed layer (Karstensen *et al.* 2015) has changed our view of current oxygen conditions in the ETNA. In that study, it was observed that the shallow oxygen minimum can reach O_2 values <2 µmol kg^{-1} (Karstensen *et al.* 2015). The authors describe several mooring transits of such eddies north of Cape Verde (CVOO station). In 2010, the moored ADCP (300 kHz, 65 to 70 m) data revealed an almost complete lack of acoustic scatterers during the passing of the eddy, which led to coining the term "open ocean dead zone". Up to now, no other biological or biogeochemical sampling exists of such an eddy in the ETNA. This has led us to conduct an interdisciplinary "eddy hunt" in spring 2014 after remotely identifying and tracking candidate eddies from summer 2013 (Löscher *et al.* 2015). The main objective of the present study was to resolve the vertical and horizontal distribution of zooplankton in relation to the oxygen concentration. To do so, we used acoustic (shipboard ADCP) and optical (Underwater Vision Profiler 5) profiling methods as well as vertically stratified plankton net hauls.

Materials and Methods
An anticyclonic mode water eddy was observed and tracked using satellite data (altimeter as well as negative SST and positive surface Chl-*a* anomalies) and first sampled using remotely operated gliders

(“remote survey”). When the eddy approached the Cape Verde archipelago, ship-based samplings (“site survey”) were conducted using the local RV “Islandia” and the German RV “Meteor” on March 6/7 and Mar 18/19, 2014, respectively (see also Löscher *et al.* 2015). The RV “Islandia” survey comprised CTD and Underwater Vision Profiler 5 (UVP5) casts inside and outside of the eddy, while the RV “Meteor” survey comprised two ADCP sections perpendicular to each other, a CTD/UVP5 cast section, and Hydrobios Multinet hauls (0.25 m^2 mouth opening, 200 µm mesh, five nets) that were worked up using a modification of the ZooScan method.

Results and Discussion

During the M105 ADCP survey, a deep scattering layer (DSL) was detected at daytime below 300 to 350 m depth and lowest target strength was recorded between 100 and 300 m depth, with a residual non-migrating population in the upper 100 m (Fig. 1). From the DSL, part of the population started its ascent to the surface layer at approximately 1600 UTC (1500 LT). The center of the nighttime distribution well outside of the eddy ranged from approximately 30 to 130m depth, and descent started around 0700 UTC (0600 LT). When traversing the eddy during nighttime, this pattern changed abruptly: The scatterers in the surface layer were located further up in the water column, their lower distribution margin coinciding with the upper oxycline (approximately 85 m in the eddy core). Habitat compression at the surface might make migrating organisms more vulnerable for predation. In contrast, organisms that are able to tolerate hypoxia may be protected from predation within the OMZ. Multinet and UVP5 data show that gelatinous plankton, in particular siphonophores, can be found in the OMZ core. In addition, several crustacean groups seem to be insensitive to OMZ conditions, including eucalanoid copepods, the cyclopoid copepod *Oncaea* sp. and ostracods. On the other hand, euphausiids (which probably contribute to the ADCP signal) were not found within the OMZ core. The term “open ocean dead zone” may be an exaggeration, such eddies certainly represent very unusual habitats within the Eastern Tropical North Atlantic, and may to some extent represent conditions of the future ocean.

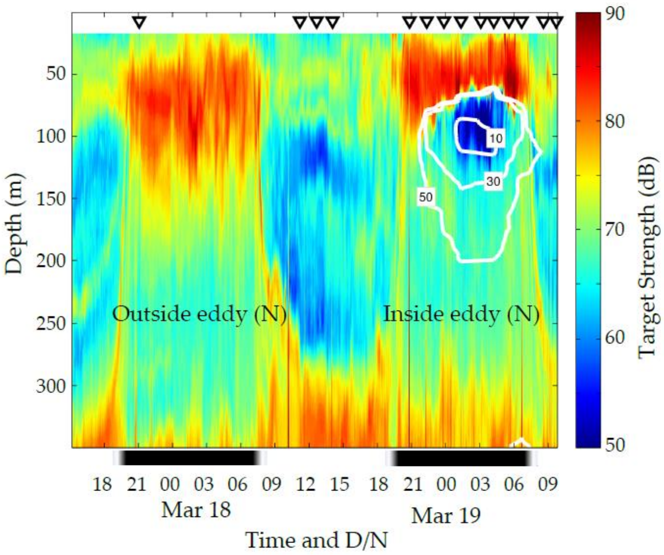

Figure 1. ADCP target strength section (colour scale) across the eddy and surrounding waters. Oxygen contours (white) are interpolated from CTD casts (indicated by triangles).

References

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