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Review

Feel good in hypoxia? – From microbes to whales, diverse life forms subsist on the "dead zone" in an enclosed bay (Omura Bay, Nagasaki) –

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Introduction

A "dead zone" represents an uninhabitable aquatic area where dissolved oxygen (DO) availability is below the limit of tolerance in aerobic organisms. As spreading of this life-threating zone has become evident in many coastal areas around the globe [1], it is urgently needed to assess responses of aquatic biota to hypoxia in order to help predict the ecosystem consequences. Omura Bay in Nagasaki is a typical enclosed bay that develops strong seasonal hypoxia (dead zone) every summer [2], yet the bay still holds rich marine resources and active fisheries. Aiming at (1) clarifying microbiological mechanisms by which dead zones are formed, and (2) obtaining quantitative understanding on how diverse types of inhabitants respond and adapt to the low oxygen condition, we began analyses of community structure and functions of micro-organisms, and monitoring distributional and behavioral patterns of macro-organisms in relation to hypoxia at the center of the bay. In this review, we briefly summarized some of the findings derived from the analyses.

Materials and methods

Sample collection
Sediment core samples have been collected by scuba diving from 2011–2015, and by a multicore sampler on board a ship (Kakuyo-Maru), in 2016 in a center region of Omura Bay (Fig. 1) during summer months (late May to early October). The DO and other parameters at the sampling site were monitored with a CTD profiler and/or logging devices.

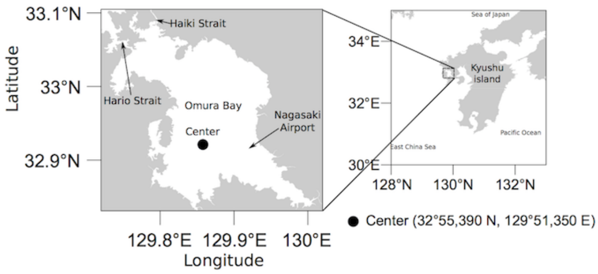

Fig. 1. Sampling location in Omura Bay.

Analysis of bacterial community
Total abundance, potential respiratory activities and community structure of sediment bacteria were determined as described in [3].

Analysis of nematode community
The top 0-10mm layers of the sediment samples were fixed and specimens within a size range of 32µm to 1mm mesh sieve were examined. Nematode specimens were identified to a genus level and further categorized into 4 feeding types [4]: (1A) selective deposit feeders, (1B) non-selective deposit feeders, (2A) epistrate (diatom) feeders, (2B) predators/omnivores.

Underwater imaging of the seafloor
Underwater pictures were taken at the center and fringe sites by a scuba diver from 2012–2016. In addition, an underwater camera was deployed at the center site in 2014 and 2015 to take video images (1 to 3 min/day) from 1 m above the seafloor.

Analysis of acoustic signal from finless porpoises
Biosonar sounds from finless porpoises were recorded at the center site using an acoustic data logger [5].

Results and discussion

DO at 1m above the sediment in the center of the bay typically started to decline below 4mg/L by mid June. Although interrupted by episodic oxygenation due to strong wind events, hypoxia continued until late September (Fig.2). Microbial mat consisting of filamentous sulfur-oxidizing bacteria was occasionally found over the seafloor during the hypoxia (Fig. 3).

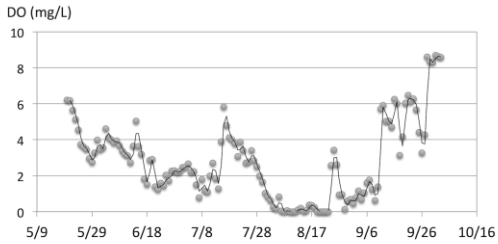

Fig. 2. Bottom DO data at 1m above the seafloor of the center site of Omura Bay during mid May through early October in 2015.

Microbial studies indicated that upper sediment in the center of Omura Bay was characterized by greater microbial community respiration and greater diversity of bacterial components compared with the non-hypoxic sediment of the bay fringe [3]. A follow-up study [6] further revealed that sediment oxygen consumption in the center site varied in response to the development of a hypoxic water mass and vertical flux of internal primary production in the water column was an important factor driving the sediment respiratory metabolism. Shifts in the bacterial community composition at the surface sediment between normoxic and hypoxic conditions were distinct and the bacterial diversity peaked at a microaerobic condition (ca. 350 $\mu gO_2/L$) (Mori et al., submitted).

Analyses on meiofauna of the surface sediment revealed (1) predominance of nematode throughout the study periods and (2) significant increase of bacterivorous nematode abundance during hypoxia (Fig.4) (Nguyen et al., unpubl. data). These findings suggest transfer of organic matter from bacteria through nematode would become more important in the sediment ecosystem in the center of Omura Bay under hypoxia than normoxia.

Video images of the seafloor have led to a discovery of a school of small pelagic fishes migrating into near-bottom water during an initial phase of the hypoxia development (Wada et al., unpubl. data), which was in contrast to the incidents of mass mortality of fish and invertebrates found at fringe sites of the bay under hypoxia.

Acoustic data logging at the center site has revealed biosonar sound from finless porpoises was recorded more frequently under hypoxic than normoxic conditions (Matsuda et al., unpubl. data). It is likely that some of the mobile predators (fish and finless porpoise) can benefit from the hypoxic condition, as it may increase vulnerability of prey organisms to them.

Conclusions

Omura Bay has provided us unique opportunities to gain insights into the responses of diverse aquatic biota to hypoxia. The present results suggest the hypoxic water mass in the bay is not simply a "dead zone", but it serves as an ephemeral "dining zone" for diverse life forms from microbes to whales.

Fig. 3. Underwater picture of microbial mat over the seafloor at the center site of Omura Bay in August, 2012.

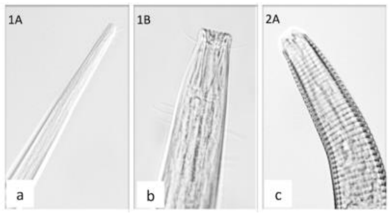

Fig. 4. Nematode specimens (a-c) representing dominant feeding types (1A, 1B and 2A) found in the sediment of Omura Bay.

Acknowledgements

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