Spatiotemporal patterns and environmental drivers of macrofauna and sediment community oxygen consumption of the Gaoping Continental Shelf off southern Taiwan

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Abstract

Keywords: Authors must provide 4 to 6 keywords plus regional index terms. At least four of the subject keywords should be selected from the Aquatic Science & Fisheries Thesaurus.

1. Introduction

* Background
  + River-influenced oceanic margins (RiOMar)
  + Stats (see thesis)
  + Role of sediment metazoans
* Theories and previous studies
  + Rhoads (1985) proposed that the benthic communities in the River-influenced oceanic margins are controlled by sedimentation stress and nutrient supplementation from the adjacent river. (elaborate)
  + Studies after Rhoads generally echoed Rhoad’s (1985) finding.
  + Loss of diversity and abundance after the river flood.
  + Changes in vertical distribution.
* Current knowledge gaps
  + To our knowledge, little attention was paid to the benthic communities at the oceanic margins adjacent to small mountainous rivers (SMR) (but see Akoumianaki et al., 2013, 2006; Akoumianaki and Nicolaidou, 2007).
  + Due to their small watersheds and steep topographies, SMRs stochastically export mass sediments into the ocean, plays and important role in global carbon cycling.
  + Furthermore, few studies have been conducted to link sediment ecosystem functioning and the marine benthos despite acknowledging their importance in sediment ecosystem functioning.
  + Climate change alters intensity and frequency of extreme weather events.
  + By expanding geographical coverage, increasing temporal resolution, and integrating ecosystem functioning measurements, researchers could better project ecological changes and the associated ecosystem response in future climate scenarios.
* Study area (extract thesis text)
  + Geographical location and geological origin of the Gaoping Continental Shelf.
  + Basic information of the Gaoping River.
  + Climate conditions, dry and wet seasons (monsoon).
  + Sediment discharge patterns of the Gaoping River (annual load).
  + Roles of extreme events, namely typhoons and earthquakes.
  + Source and fate of organic matter in this system.
* Study objective
  + The objective of this study is to document the spatiotemporal variations of the macrofauna standing stock, community assemblage, and the associated sediment oxygen dynamics.
  + Specifically, we are interested in the spatiotemporal changes of macrofaunal abundance, biomass, composition, and the sediment community oxygen consumption (SCOC).
  + We further identified environmental drivers that shaped those features of the soft sediment ecosystem.

1. Material and methods
   1. Shipboard sampling

Two cruises were conducted to collect biological and geochemical data in the Gaoping Continental Shelf (GS) (figure 1). The cruises OR1-1219 and OR1-1242 were conducted in March and October 2019, respectively. S4 was only visited in OR1-1219, while S1 and S2 were visited in OR1-1242. The rest of the four stations, namely S3, S5, S6, and S7, were revisited during the two cruises.

Between the two cruises, one typhoon, namely Typhoon Bailu made landfall in Taiwan on 1 p.m. at August 24th and caused extreme precipitation in southeast and southwest Taiwan (Lin et al., 2020). The extreme precipitation Bailu had brought caused floods and landslides. The disaster also damaged harbors and caused agricultural production loss around 170 million NTD (Lin et al., 2020). Despite mass casualties, Typhoon Bailu provided a rare opportunity to examine the response of the benthic communities to extreme weather events.

In each station, Conductivity-Temperature-Depth (CTD) sensors were deployed to collect the profiles of salinity, temperature, water transmission, fluorescence, and dissolved oxygen from the surface water to 5 m above the seafloor. The rosette bottles on the CTD also collected bottom water for sediment incubation. Multi-corers were deployed to collected. Two core tubes were sectioned into 1-cm slices from top to bottom. Each sediment slice was then portioned for analyzing geochemical signatures, such as sediment grain size, sediment porosity, and other bulk sediment compounds. Another three core tubes were chosen by their sediment length and better integrity for shipboard incubation (Glud, 2008).

The three sediment cores were incubated in a temperature-controlled water bath under dark condition to measure the sediment community oxygen consumption (SCOC). The water bath temperature was set to be within the range of the bottom water temperatures measured with CTD. Each sediment core was sealed by a plastic lid with a magnetic stir bar attached inside. After removing the air bubbles in the overlying water, another magnetic stir bar attached to a motor was placed above the plastic lid, coupling to the stir bar underneath. Both motor and magnet bars rotated and stirred the overlying water at 60 rpm to prevent water stratification. Four every 4 to 6 hours, we used a miniature oxygen optode (PreSens PSt7) to measure oxygen concentration through a small resealable sampling port and a temperature sensor (PreSens Pt100) for the water bath temperature. The oxygen optode was calibrated for each cruise by scanning the product-specific barcode. We used PreSens Microx 4 data logger to record the dissolved oxygen and temperature until the oxygen levels dropped below 85% of the initial concentration (Glud, 2008).

After incubation, a pair of Unisense oxygen microelectrodes and temperature sensors were calibrated by endpoint methods every 24 hours (Unisense A/S, 2020) and lowered into the sediment by a step motor to measure oxygen concentration profiles. The oxygen saturation endpoint was made by air-pumping the seawater with known salinity and temperature for at least 10 minutes. The oxygen depletion endpoint was made by adding sodium dithionite (Na2S2O4), a strong reducing agent, into the seawater with known volume, salinity, and temperature. Sediment oxygen concentration profiling started from roughly 1 cm above the sediment surface, with the step motor moving downward for 100 um per step until the oxygen readings of both the microelectrodes reached zero. At each step, the microelectrodes stopped for 3 seconds to stabilized themselves before taking measurements. According to Fick’s Law of Diffusion, we used the oxygen concentration profiles compensated by temperature, salinity, and sediment porosity to estimate dissolved oxygen utilization (DOU).

After sediment profiling was completed, the upper 10 cm of the sediment were sieved through a 300 um and washed with filtered seawater to retain macrofauna. The retained samples were then fixed with a 1:1 ratio of filtered seawater and a Rose Bengal-stained 10% formaldehyde solution. The fixed samples were allowed to sit at least a week before sorting and measuring for body size.

* 1. Laboratory analysis

Back in the lab, the liquid of the fixed fauna samples was replaced with 70% ethanol for long-term storage. I sorted the fauna samples into major taxa (mostly at order level) and measured their relevant body dimensions with an ocular micrometer for biomass estimation. While specimens with at least on of its main body parts (i.e., head, thorax, and abdomen) were measured, only the specimens with their cephalic region intact were included in later analysis.

Various methods were used to estimate taxon-specific biovolume. The biovolumes of polychaetes were estimated with each individual’s body shape. The body shapes of vermiform polychaetes were assumed to be cylinder, while sternaspid polychaetes were assumed to be ellipsoids. The biovolumes for some common benthic taxa were calculated using the Length-Width Relationship (LWR): V =cLW2, where V is the individual volume; c is the taxon-specific conversion factor; L and W are the maximum length and width of the individual (Feller and Warwick, 1988). The biovolumes of some odd-shaped taxa were also estimated using LWR with conversion factors borrowed from taxa with similar body shapes. The biovolumes of some other taxa with relatively simple body shapes were approximated with geometric shapes (i.e., cylinder, cone, ellipsoid) (e.g., Hillebrand et al. 1999). The rest of the taxa were assumed to be cylindrical during measurement following the general volumetric method (Benoist et al., 2019). The derived biovolumes were then converted to wet weight by assuming a specific density of 1.13 (Gerlach et al., 1985).

* 1. Data analysis

All data analysis were conducted using R version 4.0.3 (R Core Team, 2020) with additional statistical packages *vegan* (Oksanen et al., 2021), *MuMIn* (Bartoń, 2022). Packages *dplyr* and *tidyr* were used for data cleaning (Wickham, 2021; Wickham et al., 2021). Results were visualized with *ggplot2* and its extensions (Schloerke et al., 2021; Slowikowski, 2021; Wickham, 2016).

Key environmental variables were screened out with ecological reasoning and a Pearson correlation coefficient threshold of |r| > 0.7 to prevent spurious results (Dormann et al., 2013). Dissolved oxygen was excluded since all stations were well-oxygenated (Middelburg and Levin, 2009). Strong correlations were present between salinity, transmission, and temperature (|r| > 0.7); temperature was retained due to its ecological importance. Due to strong collinearity between clay, silt, sand fractions, and D50 (|r| > 0.7), D50 was selected as the sole indicator of sediment granulometry. Porosity and TN were highly correlated (r > 0.7). Since CN also indicates organic matter quality, TN was excluded. The resulting variables were *Temp*, *Fluo*, *Por*, *D50*, *TOC*, *CN*, and *Chla*. The variables were then centered and scaled to unit variance for further analysis.

Macrofauna abundance and biomass . Macrofauna abundance and biomass assemblages were Box-Cox-chord transformed (Legendre and Borcard, 2018). Unlike Hellinger transformation, which strictly takes the exponent of 0.5 on ecological data before chord transformation, Box-Cox-chord transformation provided a series of exponents for ecologists to choose from. Using Dagnelie’s test, the exponent that reaches multinormality of pairwise distances can be sought (Legendre and Borcard, 2018). In this study, the exponent for macrofauna abundance and biomass compositions were 0.3 and 0.1, respectively. Euclidean distances were then used to calculate between-sample pairwise distances.

Macrofauna composition, abundance, biomass, and SCOC were tested to seek signals of spatiotemporal patterns. While not directly measured, the distance to the Gaoping River mouth (DRM) of each station was calculated using World Geodetic System 1984. The coordinate of the river mouth was arbitrarily set at 120.423960⁰E and 22.470504⁰N using Google Map (figure 1).

The abundance and biomass composition of the sediment macrofauna were fitted using PERMANOVA with 9999 permutations. Continuous variables (Depth and DRM) and categorical variable (Cruise) with pairwise interactions

We analyzed the spatiotemporal patterns of macrofauna abundance, biomass, and SCOC with simple linear regression under the multimodel inference framework. The multimodel inference framework acknowledges that there might be multiple equally good models to describe the data, which is common in ecological research. We first built full models for the three response variables. Macrofauna abundance and biomass were log10 transformed, while SCOC were not. After that, we sought all possible combinations of the explanatory variables and extracted an un-nested top model set with ΔAICc < 6 (Richards, 2008, 2005). Using such a conservative criteria has the advantage of having parsimonious models for inference (Richards, 2008). We then took the natural average of the resulting models to seek possible ecological trends.

Strong environmental drivers of macrofauna composition, abundance, biomass, and SCOC were sought with the similar routine, except that we fit environmental variables assuming no interaction.

1. Results
   1. Environmental condition
   2. Redundancy analysis
   3. Multimodel inference
2. Discussion
   1. Study limitation
3. Conclusions
4. Acknowledgements
5. References

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