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.

Proposed keywords: River-influenced oceanic margins, continental shelf, macrofauna, oxygen consumption

1. Introduction

* Background
  + River-influenced oceanic margins (RiOMar)
  + Data (thesis first paragraph)
  + 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, OR1-1219 and OR1-1242, were conducted to collect biological and geochemical data across seven stations, namely S1 to S7, across the Gaoping Continental Shelf (GS) (figure 1). The cruises were conducted in March and October 2019, before and after the wet season. The seven stations spanned different depths and distances to the river mouth. S1, S4, and S5 have water depths ranging 85 to 93 meters, while S2, S3, S6, and S7 have water depths ranging 32 to 45 meters. 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. Despite of the unbalanced sampling design, we believe that the present dataset can show the changes of the soft sediment ecosystem varying water depths and distances to the Gaoping River mouth across time.

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 across counties in southern Taiwan. Bailu also damaged harbors, caused death and injuries, and caused agricultural production loss around 170 million NTD (Lin et al., 2020). Despite the immense damage Bailu had caused, the typhoon 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 total oxygen utilization (TOU) of the sediment. 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). We then used the following equation to estimate TOU (Song et al., 2016):

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where m is the regression slope, V is water volume, A is sediment area, and 24/1000 is a constant that adjusts TOU’s unit to mmol m-2 d-1.

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). The sediment oxygen concentration profiles were converted to the diffusive oxygen utilization (DOU) using Unisense Sensor Trace Suite software (Berg et al., 1998). The software calculates the oxygen consumption of the depth profile by intervals and then taken as the best estimator for each core. Another indicator for fauna activities, the oxygen penetration depth (OPD), was defined as the distance from the sediment-water interface to where the oxygen is depleted.

Since both TOU and DOU were measured on board, they were adjusted to *in situ* values using the temperature coefficient Q10 (Valiela, 2015).

Q10 was assumed to be 2, as for most ectotherms; Rincub. and Tincub. were the measured oxygen utilization and incubated temperature; and Tin situ was bottom water temperature. We estimated the contribution of metazoans on TOU, namely the benthic-mediated oxygen utilization (BOU), by subtracting TOU with DOU (Glud, 2008). Since BOU strongly covaried with TOU (r = 0.98), BOU was not included for later analysis. DOU measurements, on the other hand, were generally similar between samples in compare to other regions of the world, and were therefore not included for later analyses (see discussion for detailed description).

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

Median grain size (D50), sand fraction, silt fraction, and clay fractions were measured with a laser diffraction size analyzer (Model LS-13320; Beckman Coulter Inc.). Sediment porosity (Por) and water content were measured by calculating the volume and weight difference after a 100℃ for 24 hours assuming a specific density of 1.024 g cm-3 (Blum, 1997).

We measured total organic carbon (TOC), total nitrogen (TN), carbon-to-nitrogen ratio (CN), sediment chlorophyll a (Chla), and stable isotopic carbon (δ13C) of the sediments for bulk material. In brief, the sediment subsamples were first acidified with 6N HCL and then sent to the Flash 2000 elemental analyzer in tandem with a GC-Isolink interface to a Delta V Plus isotope ratio mass spectrometer (both from Thermo Fisher Scientific) to measure TOC and δ13C. TOC values were reported in percent weight contribution, while δ13C values were calculated using Vienna-PeeDee Belemnite as the reference point and reported in ‰ differences. TN measurements were similar to TOC and δ13C except no acid pretreatments were applied before sending the sediment samples into the same instruments. CN was then derived by dividing TOC with TN. For Chla, the sediment samples were first sitting in 10-ml acetone-water solution with a volumetric ratio of 9:1 in the dark at 4℃ for 24 hours. The chlorophyll extracts were then measured with a fluorometer (Model 10-AU; Turner Designs, Inc.) and reported in nanogram per gram dry weight.

Back in the lab, the liquid of the fixed fauna samples was replaced with 70% ethanol for long-term storage. Fauna samples were sorted into major taxa (mostly at order level) and measured with an ocular micrometer for biomass estimation. 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):

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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) and reported with the language of evidence (Muff et al., 2022). P values ranging from 0.001 to 0.0001 provide very strong evidence, while p values ranging from 0.01 to 0.001 indicate strong evidence. P values ranging from 0.05 to 0.0, from 0.1 to 0.05, and from 1 to 0.1 indicate moderate, weak, and no evidence, respectively.

We divided explanatory variables into (1) spatiotemporal factors and (2) environmental variables to seek spatiotemporal patterns and identify environmental drivers separately. Although not directly measured, the distance between each station and the Gaoping River mouth (DRM) 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). Each of the environmental variables were subjected to examine whether the differed between cruises. After that, 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 selected into further analysis due to its cross-scale ecological importance (Brown et al., 2004). 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 other geochemical indicators, such as CN and Chla, also indicate organic matter quality (Campanyà-Llovet et al., 2017), TN was excluded in later analyses. δ13C and Chla were negatively correlated (r = -0.76). Chla was included for further analyses since δ13C signatures may be confounded by marine autochthonous carbon, modern terrestrial carbon, and petrogenic carbon in the present study area (Carter et al., 2012; Kao et al., 2006, also see discussion). The resulting variables were *Temp*, *Fluo*, *Por*, *D50*, *TOC*, *CN*, and *Chla*. The variables were centered and scaled to unit variance. Two axes of the principal component analysis (PCA) were extracted to visualize the environmental difference among sampling sites.

Macrofauna abundance and biomass assemblages were Box-Cox-chord transformed (Legendre and Borcard, 2018). While Hellinger transformation strictly takes the exponent of 0.5 on ecological data before chord transformation, Box-Cox-chord transformation is more flexible, providing a series of exponents for ecologists to choose from. Using the Dagnelie test, the exponent that reaches multinormality of the Mahalanobis generalized distance, i.e., the distance between each object and the multivariate mean, 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 distance was then used to calculate between-sample pairwise distances. The first two axes of the principal component analysis (PCA) were used to visualize the compositional difference between samples. Only taxa with 40% of their variation explained by the first two PCs were shown. On the other hand, macrofauna abundance and biomass were log10 transformed, while TOU were not. Scatterplots were then drawn to show spatiotemporal variations among stations.

Water depth, DRM, and Cruise with all possible two-way interactions were fitted on (1) macrofauna abundance composition, (2) biomass composition, (3) abundance, (4) biomass, and (5) TOU to examine spatiotemporal patterns. We used PERMANOVA with 9999 permutations on macrofauna abundance and biomass compositions (Anderson, 2017), while we fit simple linear regressions on macrofauna abundance, biomass, and sediment TOU under the multimodel inference framework. Preventing arbitrarily selecting a single model for inference, the multimodel inference framework uses information theoretic approaches to account uncertainty across several models, identifies competing models, and then draws inferences from them (Burnham and Anderson, 2002). 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 disregarding overly complex models, which include more variables without notable decrease in AICc values (Richards, 2008). We then took the natural average of the resulting models to seek ecological trends (Burnham and Anderson, 2002).

Environmental variables were fitted on macrofauna abundance composition, biomass composition, abundance, biomass, and TOU to identify potential drivers, except that we assume no interactions between those variables. Redundancy analysis (RDA) with p-value-based backward selection were used to retain a set of environmental variables that best described the compositional data. Only taxa with 40% of their variation explained by the first two RDA axes were shown. Macrofauna abundance, biomass, and TOU, similar to what we described above, were also fitted with environmental variables with simple linear regression under a multimodel framework.

1. Results
   1. Environmental condition and macrofauna

CTD profiles showed notable temporal variations (figure 2). Temperature, salinity, density, oxygen, and fluorescence profiles in OR1-1219 showed little variation across depths and between stations. In contrast, temperature, salinity, and density, profiles in OR1-1242 displayed noticeable stratification patterns, with warm, brackish, light water occupied the upper water column and cold, saline, heavy water located at the lower water column. The variations of transmission profiles in OR1-1219 mainly occurred at the deeper water column, while those variations in OR1-1242 were present throughout the water column.

PC1 and PC1 of the environmental variables explained 36.6 and 25.6% of the total variation (figure 3). PC1 was loaded with high contributions of *Temp*, *Fluo*, *Chla*, and *CN*. PC2 was loaded with *TOC*, *Por*, and *D50*. Shallower stations of OR1-1242 (S2, S3, S6, and S7) were aggregated at the right-hand side of the PCA figure, while deeper stations in OR1-1242 and all stations in OR1-1219 aggregated at the left-hand side of the PCA.

* 1. Macrofauna assemblage

We found 27 taxa belonging to phylum Annelida, Arthopoda, Cnidaria, Echinodermata, Mollusca, Nematoda, Nemertea, Phoronida, Platyhelminthes, and Vertabrata. Across all 27 taxa, polychaetes dominated macrofauna abundance and biomass across all stations, contributing 39.43-70.22% and 6.29-82.45% of overall abundance and biomass (figure 4). In terms of abundance, amphipods and nematodes also contributed greatly to macrofauna abundance, occupying 1.27-39.00% and 3.55-21.05% of abundance across all stations, respectively (figure 4a). On the other hand, ophiuroids and decapods contributed greatly to macrofauna biomass, accounting 0-81.16% and 0-81.73%, respectively (figure 4b). While the overall density assemblage did not vary among stations, variations in ophiuroid and decapod biomass were evident in macrofauna biomass assemblage.

PERMANOVA tests revealed notable spatiotemporal variations in macrofauna abundance and biomass compositions (Table 1). For abundance composition, we found very strong evidence with depth (p = 0.0001) and DRM (p =0.0002). We found moderate evidence in cruise differences (p = 0.0458) and DRM-cruise interactions (p = 0.0440). There was weak evidence in depth-DRM interactions (p = 0.0884). Depth-cruise interactions had no evidence on abundance composition (p = 06904). For biomass composition, we only found very strong evidence in depth (p = 0.0001). We found strong evidences DRM (p = 0.0092) and DRM-cruise interactions (p = 0.0014). Moderate evidence was found in cruise effect (p = 0.0208). There was no evidence in depth-cruise (p = 0.8016) and depth-DRM interactions (p = 0.2512).

Principle component analyses generally agreed with the PERMANOVA results, revealing complex spatiotemporal assemblage variations (figure 5). PC1 and PC2 of the macrofauna abundance composition explained 18.14 and 15.94% of the total variation (figure 5a). More the 40% of the variation of peracarids (isopods, tanaids, and amphipods), aplacophorans, and hydroids were explained in the first two PCs. OR1-1219 samples were mostly characterized with high contributions of aplacophorans, tanids, and amphipods, while shallower-water OR1-1242 samples (S2, S3, S6, S7) were not. PC1 and PC2 of the macrofauna biomass composition explained 20.57 and 13.69% of the total variation (figure 5b). More the 40% of the variation of aplacophorans, mysids, ophiuroids, and decapods were explained by the first two PCs. In contrast with the abundance composition PCA figure, the distribution of samples better corresponded with the taxa vectors. Many OR1-1219 sites and deeper OR1-1242 sites (S1, S5) were characterized with high contributions of ophiuriods and aplacophorans. On the other hand, Shallower OR1-1242 sites (S2, S3, S6, and S7) were characterized with high contributions of mysids and decapods.

Regarding environmental drivers of macrofauna assemblages, RDA analyses displayed similar features between the abundance and biomass compositions (figure 6). RDA explained 31.44% of macrofauna abundance composition’s variation, while RDA1 and RDA2 explained 40.85 and 27.65% of that variance, respectively (figure 6a). *D50*, *Por*, *Chla*, *TOC*, and *CN* were retained in the final RDA model. More than 40% of the variation of oligochaetes, mysids, and aplacophorans were explained by the first two RDA axes. RDA explained 34.35% of macrofauna biomass composition’s variation, while RDA1 and RDA2 explained 43.02 and 26.04% of that variance, respectively (figure 6b). *D50*, *Temp, Por*, *Chla*, *TOC*, and *CN* were retained in the final RDA model. More than 40% of the variation of Decapods, mysids, and aplacophorans were explained by the first two RDA axes. The two RDAs agreed upon that *TOC*, *CN*, and *Chla* were the main environmental variables that drove the assemblage differences among S4, S5, S6, and S7 of OR1-1219 and OR1-1242. On the other hand, S1 and S3 of OR1-1242 were distinct from the organic matter gradient. The macrofauna assemblage of S1 in OR1-1242 was characterized with high *D50*, while that of S3 in OR1-1242 was characterized with high *Por* and mysid contributions. The main difference between the two RDAs is that the biomass RDA specifically showed in influence of *Temp* on the shallower OR1-1242 sites (S2, S3, S6, S7).

* 1. Macrofauna abundance, biomass, and TOU

The average macrofauna abundance across all samples was 8,966.69 ± 4,144.15 ind. m-2, with S7 in OR1-1242 having the lowest abundance of 4,626.10 ± 265.05 ind. m-2 andS3 in OR1-1219 having the highest abundance of 19,480.57 ± 1,836.29 ind. m-2 (figure 7). The average biomass, on the other hand, was 29.93 ± 34.04 g m-2, with S3 in OR1-1242 having the lowest biomass of 1.74 ± 0.81 g m-2 and S1 in OR1-1242 having the highest biomass of 93.61 ± 13.04 g m-2. The average TOU in the present study is 15.59 ± 7.37 mmol O2 m-2 d-1, with S5 in OR1-1219 having 7.97 ± 0.90 mmol O2 m-2 d-1 and S3 in OR1-1242 having 29.15 ± 2.58 mmol O2 m-2 d-1.

The averaged models of macrofauna abundance, biomass, and sediment TOU showed strong spatiotemporal variations (table 2). In the averaged macrofauna abundance model, there was very strong evidence that macrofauna abundance varies with Cruise (β = -0.2413, p < 0.0001), DRM (β = -0.1512, p = 0.0001), and Cruise-DRM interaction (β = 0.1555, p = 0.0001). There was strong evidence of Cruise-Depth interaction (β = 0.1238, p = 0.0036), moderate evidence of Depth-DRM interaction (β = 0.0618, p = 0.0265), and weak evidence of Depth (β = -0.0632, p = 0.0551) affecting macrofauna abundance. In the averaged macrofauna biomass model, there was very strong evidence that macrofauna biomass varies with Cruise-DRM interaction (β = 0.7440, p = 0.0007). There was moderate evidence in DRM on macrofauna biomass (β = -0.3395, p = 0.0484). There was no evidence in Cruise on macrofauna biomass (β = 0.17, p = 0.4054). In the averaged TOU model, there was strong evidence in Cruise (β = 4.4799, p = 0.0137), DRM (β = -2.3824, p = 0.0200), and Cruise-Depth interactions (β = -4.2756, p = 0.0393). On the other hand, Depth alone has little evidence on macrofauna biomass (β = -2.5605, p = 0.1572). The model average results of the spatiotemporal patterns generally echoed with the scatterplot, with obvious interactions between spatial (DRM and depth) and temporal factors (cruise) (figure 7).

Model averaging results revealed that the seafloor environment notably influenced macrofauna abundance, biomass, and sediment TOU (table 3). In the averaged abundance model, *CN* (β = 0.1054, p < 0.0001), *D50* (β = -0.0687, p = 0.0001), and *TOC* (β = 0.2143, p < 0.0001) had very strong evidence on affecting macrofauna abundance. There was strong evidence that *Por* (β = -0.1542, p = 0.0023) and *Temp* (β = 0.0713, p = 0.0067) negatively and positively affecting abundance, respectively. There was moderate evidence on *Chla* negatively on affecting macrofauna abundance (β = -0.0743, p = 0.0329). In the averaged biomass model, *Chla* (β = -0.9165, p = 0.0055), *CN* (β = -0.8093, p = 0.0037), and *Temp* (β = 0.5190, p = 0.0086) had strong evidence on affecting macrofauna biomass. The data revealed moderate evidence that macrofauna biomasswas positive associated with *D50* (β = 0.3918, p = 0.0251) and *TOC* (β = 1.7240, p = 0.0272), while that was negatively associated with *Por* (β = -1.6368, p = 0.0109). There was weak evidence that *Fluo* negatively associated with macrofauna biomass (β = -0.2033, p = 0.0929). In the averaged TOU model, there was very strong evidence that Temp (β = 5.6855, p < 0.0001), CN (β = 8.2232, p < 0.0001), and Por (β = 14.79884, p < 0.0001) positively influenced TOU. *Chla* had moderate evidence in positively influencing sediment TOU (β = 6.8446, p = 0.0005). The data showed very strong and strong evidence that TOC (β = -17.4794, p < 0.0001) and D50 (β = -4.0338, p = 0.0005) negatively associated with TOU, respectively.

1. Discussion
   1. Study limitation
   2. Environmental data

Discharge dynamics of the Gaoping River drastically changed the water column structure and the seafloor condition of the Gaoping Continental Shelf. In contrast the to the stable CTD profiles in OR1-1219, higher temperature and lower salinity in the surface waters of OR1-1242 indicated the intrusion for the riverine waters (figure 2). While the bottom water light transmission variations in OR1-1219 indicated tidal-current driven sediment resuspension events (Liu et al., 2002), the stochastic transmission variation throughout the OR1-1242 column indicated additional particulate inputs from the Gaoping River (figure 2). Furthermore, higher fluorescence and lower transmission in S2 surface water matched previous satellite observations, indicating an ongoing Gaoping River plume event (Liu et al., 2009). Considering the seafloor conditions, shallower stations in OR1-1242 were associated with higher bottom water temperature, which was highly correlated with salinity and transmission, indicating that the inner shelf seafloor was influenced by the riverine waters. Both the CTD profiles and the PCA figure indicated strong influences of the Gaoping River on the environmental condition of the continental shelf.

Presence of the influence of typhoons.

One puzzling pattern is the strong negative correlation between δ13C and Chla in the Gaoping Continental Shelf. As the carbon stable isotopic fractions of terrestrial C3 plants and marine algae were known to be around -27‰ and 20-22‰, respectively (Meyers, 1994 and references therein), the higher δ13C in surface sediments collected in OR1-1242 indicated an enrichment of marine organic matter (-24.6 to -24.2‰ vs -24.4 to -23.6‰). On the other hand, the concentration of sediment chlorophyll a was notably lower in OR1-1242 (673-1,246 vs 165-478 ng/g dry), suggesting that marine organic carbon was less abundant. While the reasons were unclear, we speculate that sediment dilution and input of fossil organic carbon .

A modelling study pointed out that.

The other possible factor is that fossil organic carbon originated from the Taiwan Orogen, which have δ13C ranging from -20 to -25‰ (Hilton et al., 2010), could further complicate the sources of organic carbon (Kao et al., 2014).

While C4 plants were present in the Gaoping River catchment and could potentially affect the , previous studies found the C4 plant organic matter are negligible in the continental margin (Zheng et al., 2017). These results suggested that carbon stable isotope alone could not indicator of organic matter origin in the Gaoping Continental Shelf.

* 1. Spatiotemporal changes of and sediment oxygen dynamics
* paradoxical patterns of TOU increase and abundance/biomass decrease.
* Changes in environmental condition predominates oxygen consumption.
* Current data does not show what consumes the oxygen in OR1-1242.
  1. Changes in the physical environment correlated
* Porosity
  + Porosity had a strong negative effect on macrofauna abundance and biomass (table 3).
  + Porosity increased in all of the revisited stations, indicating a shelf-wide change of the physical environment (supp. table).
  + The Gaoping River was known to discharge mass sediments after typhoons, covering the continental shelf with flood deposits (Huh et al., 2009).
  + Similarly, macrofauna abundance on the Eel River Continental Shelf reduced XXX to XXX% after intense flood sedimentations characterized with high clay fraction and porosity (Wheatcroft, 2006; Wheatcroft et al., 1996).
  + While porosity had a strong negative effect on macrofauna abundance and biomass over the study area (table 3), its effect on macrofauna assemblage was localized. In the OR1-1242 samples, the macrofauna assemblages of S5, S6, and S7 were mainly associated with changes of sediment organic matter indicators such as Chla, TOC, and CN (figure 6). On the other hand, the macrofauna assemblage of S3 strongly varies with sediment porosity. Nevertheless, the macrofauna assemblage of S3, S5, S6, and S7 were all influenced by bottom water temperature, which indicated the presence of the hot, brackish, muddy river water (figure 6b). As S3 being the closest station to the river mouth, the influence of riverine input likely varied with the distance to the Gaoping River mouth.
  + As, positive influences of D50 on macrofauna biomass indicating a more stable environment for the sediment fauna.
  1. Organic matter indicators
* While CN and δ13C were often used to identify the source and quality of the organic matter, .
* Chla and δ13C were negatively correlated (r = -0.76).
* Similarly, Akoumianaki et al. (2013) reported a weaker fit between biological and environmental data during flood season.
* Although greater quality and quantity of organic matter nurtures the seafloor biota (Campanyà-Llovet et al., 2017), the increase of organic matter quality and quantity more or less indicated the sedimentary condition of the seafloor.
* With a lifespan ranging months to years, the change of macrofauna in the present study xxxxxx.
  1. Oxygen dynamics

The measured DOU in the present study might not be representative to *in situ* conditions. DOU measurements in the Gaoping Continental Shelf were lower than the Rhone River delta (cit.), and other deltaic regions. *In situ* DOU measurements off the Rhone river have shown that sediment resuspension events could increase DOU to the factor of 2 within an hour; DOU would then 36 hours to return to its stabilizing state (Toussaint et al., 2014). Since the Gaoping Continental Shelf seafloor receives inputs from the Gaoping River and is subjected to tidal waves (Liu et al., 2002), it was likely that DOU can be as dynamic as in the Rhone river deltaic sediments. In fact, bottom water transmission dips in OR1-1242 indicated possible sediment resuspension events at the shelf seabed (figure 2). Also, oxygen profile measurements in the present study were done after sediment incubation, which generally took more than 24 hours, giving DOU enough time to drop back to the normal state. We therefore speculate that the DOU measured in the present study is systematically lower than those *in situ*. We warn that incubation experiments might stabilize the sediment, lowering the measured DOU, yielding erroneously high BOUs as a result. Also, future studies should specify when their oxygen profiles were measured.

While porosity negatively affects macrofauna abudance and biomass, porosity was positively associated with TOU.

Flooded sediments were also known to have higher organic matter content (Avnimelech et al., 2001).

1. Conclusions
2. Acknowledgements
3. References

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