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Organic Balance in a Subtidal Benthic Community of the Marian Cove, King George Island, South Shetland Islands, Antarctica

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ABSTRACT. Vertical flux of organic particles and benthic community respiration were directly measured at the Marian Cove, King George Island, Antarctica in an austral summer. For the direct measurement of the particle flux and the benthic respiration, near-bottom sediment traps and benthic chambers were deployed on the bottom at about 25 m below the surface of the cove from Dec. 26, 1994 to Jan. 15, 1995. Primary production in the surface waters and of benthic microalgae was also measured. The vertical flux of organic particles into the benthic community was low (55 to 166 mg C m^{-2} d^{-1}). The benthic respiration rate directly measured at the benthic community, however, showed high oxygen consumption rate (400 to 800 mg O_2 m^{-2} d^{-1}), which is equivalent to organic demand of 127.5 to 255.0 mg C m^{-2} d^{-1}. Benthic microalgae, on the other hand, showed high primary production (ca. 180 mg C m^{-2} d^{-1}) even under 1% light condition. Organic particles supplied from the water-column alone could not sustain the organic demand of the benthic community of the Marian Cove. The benthic microalgal production might be responsible for balancing between the low organic supply from the surface and the high organic demand of the benthic community at least during the 94/95 austral summer.

Key Words: Antarctica, benthic chamber, benthic microalgae, benthic respiration, mass balance of organic carbon, particle flux

Introduction

Supply of organic matter to the benthos is a major factor influencing benthic community structure, biomass, and metabolism (Rowe 1969; Smith 1987; Grebmeier *et al.* 1988, 1989). Previous studies have shown a direct relationship between particulate organic matter flux to the benthos and planktonic production in the surface waters of the ocean (Eppley and Peterson 1979; Davies and Payne 1984).

The Antarctic Ocean is the largest one of the high nutrient regions of the oceans. However, the Antarctic Ocean is now thought to be much less productive than was believed before, and the major part of the ocean is one of the less productive marine systems (see Treguer and Queguiner 1991). Nevertheless, many studies have reported a rich benthic fauna in the Antarctic Ocean (Grebmeier *et al.* 1989; Grebmeier and Barry 1991, references therein).

Clarke (1985, 1987) suggested that the high biomass of Antarctic benthos was a result of the low metabolic rate of the Antarctic benthic animals. Slow growth, delayed maturation, and long life span of Antarctic benthos make it possible to accumulate high biomass of benthic communities. It is, however, suggested that the low metabolism of Antarctic benthos is not a result of low temperature, but a result of food limitation (Nedwell *et al.* 1993).

Horizontal advection of phytodetritus from the productive shelf regions to the deep-sea floor was

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*corresponding author (yckang@kordi.re.kr) also suggested to explain the high benthic biomass of the Arctic fauna (Grebmeier *et al.* 1988; Feder *et al.* 1994). In the Antarctic Ocean, however, the lateral transport of organic matters from the shelf to the deep-sea floor was not confirmed yet. Feder *et al.* (1994) suggested another food sources such as benthic diatoms in a shallow coastal area and bacterial productions in the sediment.

Low primary production in the surface waters and relatively high benthic biomass had been also observed in the Marian Cove, King George Island, Antarctica until a recent austral summer (Kang 1989; Yang 1990; Ahn and Kang 1991; KORDI 1995). Thus the problem pending in the Antarctic seas, 'high benthic biomass despite low water-column primary production' could be a question for the Marian Cove (refer Table 1).

In this study, the discrepancy between low primary productivity in the surface waters and high benthic biomass was addressed in an Antarctic coastal waters. In order to quantify the organic balance between the supply and the benthic demand, direct measurement of the settling flux of organic particles and the benthic oxygen respiration rate was firstly attempted in an Antarctic coastal area during an austral summer (refer Figs 1 and 2).

Table 1. (A) Water-column primary productivities in various Antarctic regions. The Marian Cove and the Maxwell Bay show relatively low primary productivities. (B) Benthic biomass values in various Antarctic regions. The Marian Cove shows a relatively high benthic biomass value

(A)

Location	Primary productivity ($g\ C\ m^{-2}\ d^{-1}$)	Source
Gerlache Str.	3.20	reviewed by El-Sayed (1984)
Deception I.	3.62	
Signy I.	2.80	
Ross Sea	1.00	El-Sayed et al. (1983)
Maxwell Bay	0.30	Yang (1990)
Marian Cove	0.53	This study

(B)

Location	Depth(m)	Biomass ($g\ m^{-2}$)	Source
Kerguelen	6 - 30	<100 - 3000	reviewed by Picken (1985)
Signy I.	6 - 30	200 - 4000	
Haswell I.	15 - 200	<100	
S. Shetlands	30 - 200	200 - 300	
Marian Cove*	80 - 100	>1000	Kang (1989)

* a lot of *Sterechinus neumayeri* and *Laternula elliptica* was observed at 20-30 m depth of the Marian Cove.

Materials and Methods

Settling flux of organic particles and benthic oxygen respiration

For the direct measurement of the settling flux of organic particles and benthic oxygen respiration, original benthic chambers and near-bottom sediment traps (refer Kang and Shim 1997; Kang 1998) were deployed on the Chamber Site, the bottom at about 25 m below the surface of the Marian Cove, King George Island, Antarctica (Fig. 2).

Settling flux of organic particles was estimated from the amount and the organic content of the trapped sediments accumulated inside of the traps. Benthic oxygen respiration rate was calculated from the evolution of dissolved oxygen in the chamber waters during the benthic *in situ* incubation experiment. The following is the simple equation for the calculation of benthic oxygen respiration rate,

$$R = (dC/dt)^*(V/S) = (dC/dt)^*h$$

where, R is benthic oxygen respiration rate (moles $m^{-2}\ d^{-1}$*),*
dC is concentration change of oxygen (moles m^{-3}*),*
V is the volume confined by the benthic chamber (m^3*),*
dt is the time ellapsed (day),
S is the area confined by the benthic chamber (m^2*),*
h is the chamber height (m).

Primary production in the surface waters and of the benthic microalgae

Primary production in the surface waters and of the benthic microalgae was measured through incuba-

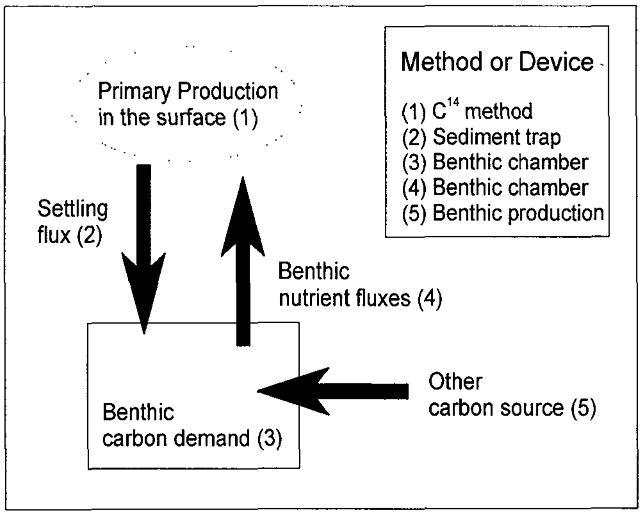


Fig. 1. Schematic diagram showing the objectives of this study. For the direct measurement of benthic organic demand and supply a benthic flux chamber and a near-bottom sediment trap were firstly introduced to an Antarctic coastal environment. Organic supply from the surface was measured from downward flux of settling particles, and benthic organic demand was converted from the benthic oxygen uptake rate. Primary production in the surface and of the benthic microalgae was determined by C^{14} method.

tion experiments during the study period. Radiocarbon method was adopted for the productivity measurement (Parsons *et al.* 1984). Surface waters were incubated under 100% natural light condition, while the sediment taken from the Chamber Site were incubated with ambient bottom water under 1% light condition, which was similar to the light intensity of the Chamber Site. C^{14} labelled $NaHCO_3$ solution (each 5 microcuri) was added to each sample incubation bottle, and the samples were incubated under ambient water temperature. The samples were filtered immediately after incubation, and the radioactivities of the filters were measured with LKB Wallac liquid scintillation counter (model 1215 Rackbeta II).

Chemical analyses of the chamber and ambient water properties

The changes of dissolved oxygen concentrations both in the chamber and in ambient waters were continually monitored with an oxygen probe (YSI 3800 Water Quality Logger). For the analyses of the nutrients including ammonium, water samples were continually taken both from the benthic chambers and from the ambient waters with a set of 50 ml syringes (Kang and Shim 1997). The waters were immediatly filtered with an acrodisc of 0.2 μm pore size to remove particles (refer Lee *et al.* 1995), and the filtered waters were frozen at –20°C for the later analyses. The concentrations of the ammonium, nitrate, nitrite, phosphate, and silicate ions in the water samples were determined with an automated ion analyzer (LaChat model QuickChem AE).

Vertical profiles of temperature and salinity of the overlying waters above the Chamber Site were obtained with a multisensor pack (YSI 3800 Water Quality Logger). The daily variation of temperature and salinity in the surface waters was also monitored with the sensor pack.

Results and Discussion

Evolutions of physical and chemical properties in the surface and in the chamber waters

Temperature, salinity, and dissolved oxygen concentrations in the surface waters showed almost constant values during the study period (Fig. 3a), and changed a little vertically (Fig. 3b). Dissolved oxygen and ammonium concentrations in the ambient bottom waters also changed a little during the benthic *in situ* experimental period (Fig. 4, Ambient Bottom Waters). From these results, it could be deduced that there was no abrupt environmental change around the Chamber Site during the study period.

There were, however, dramatic changes of the chamber water properties during the benthic *in situ* incubation experiment (Fig. 4, Chamber-A and Chamber-B). Concentration of dissolved oxygens in the chamber waters decreased with time, while ammonium concentrations increased with time. It was a result of sediment oxygen consumption and decomposition of organic matters in the sediments inside of the chambers. (Evolution of nutrient concentrations in the chamber waters was not discussed in this manuscript. Nutrient flux will be discussed in another manuscript by the authors).

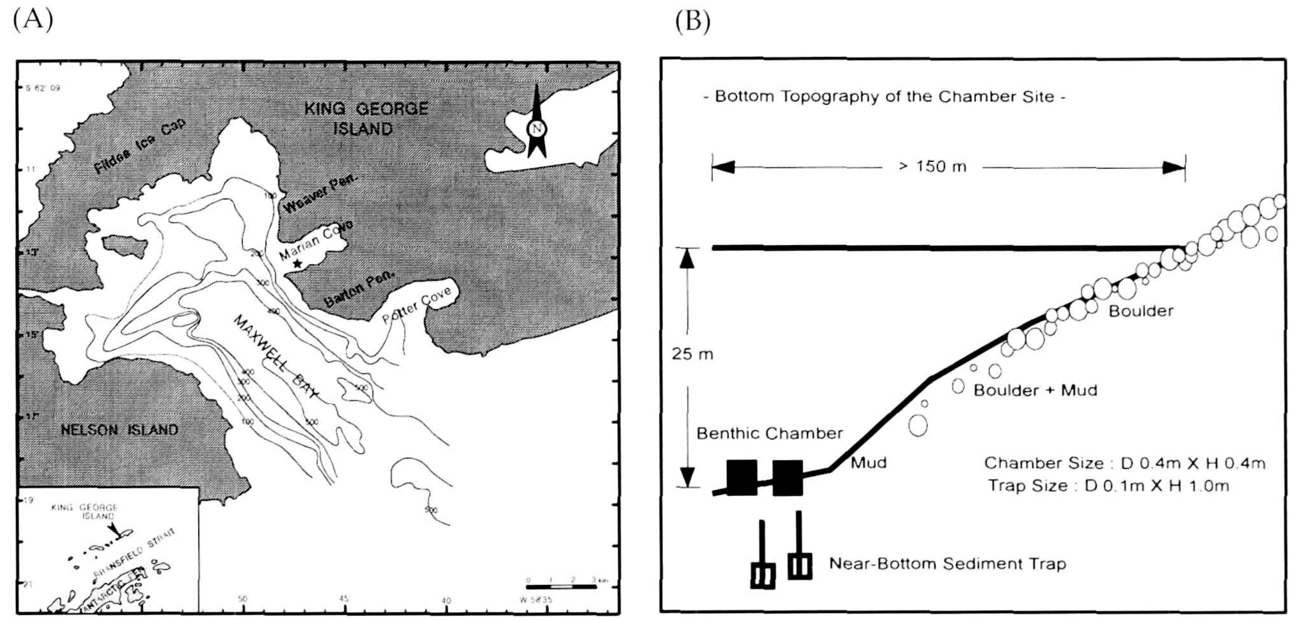


Fig. 2. (A) Location of the study site at the Marian Cove, King George Island, Antarcitca. Marian Cove is a small bay in front of Korean King Sejong Station. The cove is a typical U-shaped fjord with maximum depth of about a hundred meter. Star symbol indicates the Chamber Site, the benthic experimental site of the cove. (B) Schematic diagram showing the Chamber Site. Benthic flux chambers and near-bottom sediment traps were deployed on the bottom at about 25 m below the surface for the benthic in situ incubation experiment from Dec. 26, 1994 to Jan. 15, 1995.

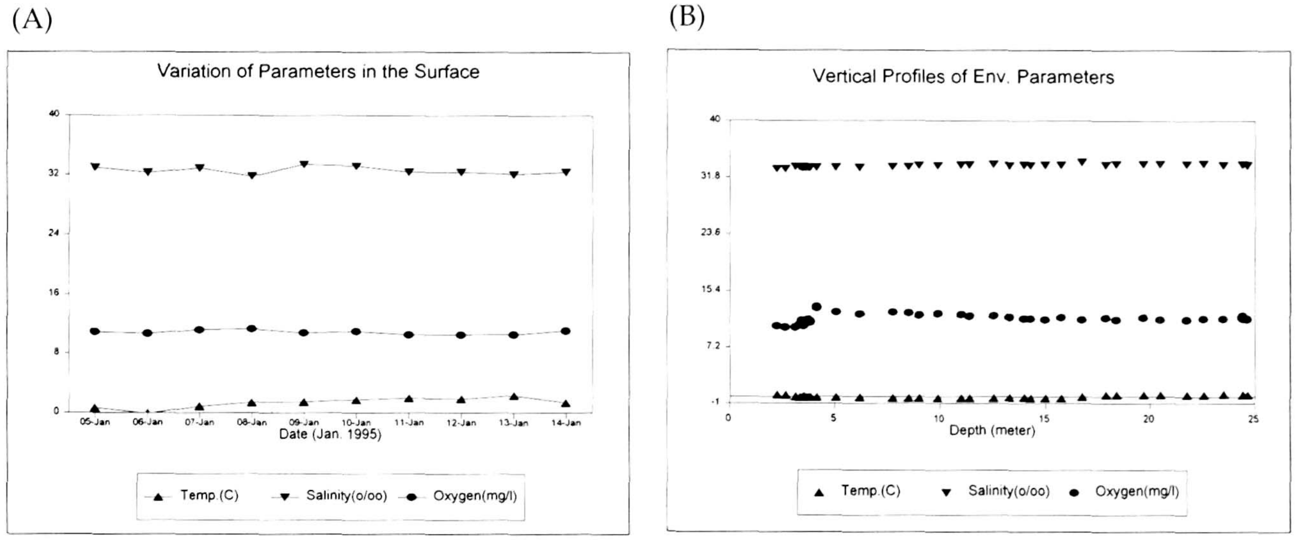
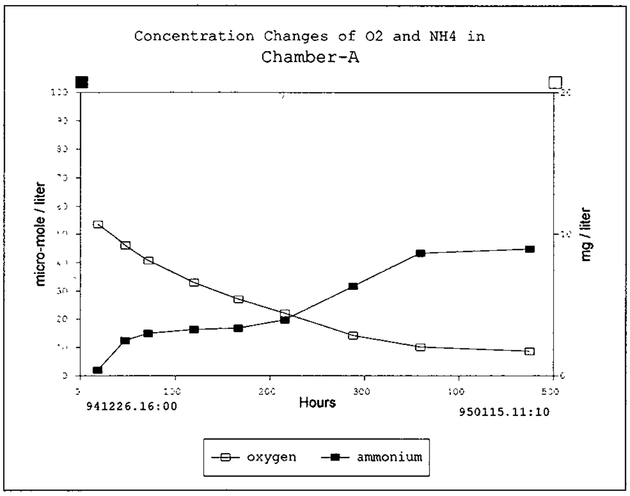


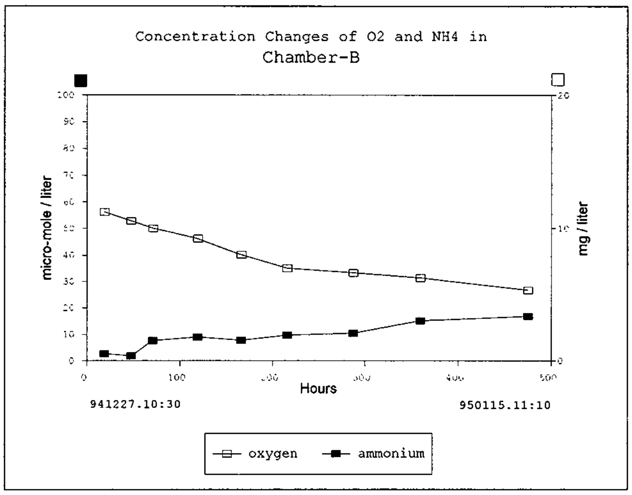
Fig. 3. Variations of environmental parameters in the surface and the overlying waters during the benthic *in situ* incubation experiment at the Chamber Site in 94/95 austral summer. (A) Daily variation of temperature, salinity, and dissolved oxygen in the surface waters around the Chamber Site. (B) Vertical profiles of environmental parameters in the overlying waters above the Chamber Site.

Settling flux of organic matters and benthic oxygen respiration rate

Settling flux of organic particles into the Chamber Site ranged between 154 mg m^{-2} d^{-1} and 464 mg m^{-2} d^{-1} (Table 2). This result was roughly coincident with those of other workers measured by different types of sediment traps moored in the water columns of the Marian Cove (Hong 1989; Ahn 1993).

Benthic oxygen consumption rate directly measured at the Chamber Site showed values between 400 mg O$_2$ m^{-2} d^{-1} and 800 mg O$_2$ m^{-2} d^{-1} in the Chamber A, and between 200 mg O$_2$ m^{-2} d^{-1} and 1300 mg O$_2$ m^{-2} d^{-1} in the Chamber B (calculated from 1st





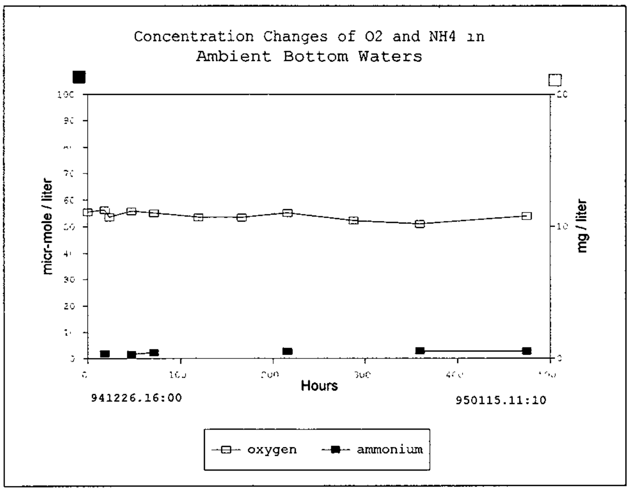


Fig. 4. Concentration changes of dissolved oxygens and ammonium ions in the chamber waters during the benthic *in situ* incubation experiments at the Chamber Site of the Marian Cove in 94/95 austral summers. Rapid depletions of dissolved oxygens were observed in the chambers during the benthic experimental periods, while the ambient bottom water showed relatively constant values.

Table 2. Settling flux of organic particles measured at the Chamber Site during the benthic *in situ* experimental period in the 94/95 austral summer and previous works measured by other workers at the Marian Cove

	Depth	Duration	Trapped Matter (mg)			Org. Flux	Note
			Total	Organic	(%)	(mg m^{-2} d^{-1})	
Chamber site	15 m	167.8h	1060	44.03	(4.15)	366	M
	15 m	167.8h	2650	117.73	(4.44)	979	M
	25 m	427.5h	3142	64.89	(2.06)	464	B
	25 m	403.5h	1153	20.34	(1.76)	154	B
Marian Cove	20 m	10 days	31.6 mg m^{-2} d^{-1}	-	(0.523)	165	Ahn (1993)
	20 m	-	35.0 mg m^{-2} d^{-1}	-	-	-	Hong (1989)

*M-type: mouth diameter 14.8 cm (area 172 cm^2), height 55 cm, from Dec. 26, 1994 to Jan. 2, 1995

*B-type: mouth diameter 10.0 cm (area 78.5 cm^2), height 100 cm, from Dec. 28, 1994 to Jan. 15, 1995

day and 2nd day changes of the oxygen concentrations in the chamber waters, refer Table 3). The benthic oxygen uptake rate of the Chamber Site seemed to be roughly coincident with those of other areas except those of Signy I. (summer) (Nedwell et al. 1993) and Long I. Sound (Mackin and Swider 1989)(Table 4).

Table 3. Benthic oxygen respiration rate measured at the Chamber Site during the benthic *in situ* incubation experiments in the 94/95 austral summer. The daily-rates were calculated based on the concentration changes of dissolved oxygens in the benthic incubation chambers. Unit is mg O_2 m^{-2} d^{-1}

Date	Chamber-A	Chamber-B
d2	844.8	1324.8
d3	412.0	228.0
d4	428.0	312.0
d5	314.0	236.0
d7	241.0	212.4
d9	199.8	68.5
d12	208.0	48.0
d15	110.7	125.3

Table 4. Benthic oxygen uptake rates in various coastal sediments

Period	Location	Rate (mmol O_2 m^{-2} d^{-1})	Source
Summer	Signy I.	80-90	Nedwell and Walker (1995)
	Long I. Sound	81-137	Mackin and Swider (1989)
	Thai mangrove swamp	17-61	Kristensen *et al.* (1991)
	North Sea sediment	10-30	Nedwell *et al.* (1993)
Annually	Signy I.	12.3	Nedwell and Walker (1995)
	North Sea sediment	2.8-4.6	Nedwell *et al.* (1993)
	Marian Cove (summer)	12.5-25.6	This work

Organic production, supply, and demand at the Chamber Site

Primary production measured in the surface waters, settling flux of particulate organic matter, benthic organic demand converted from the benthic respiration rate (respiratory quotient (CO_2/O_2) = 0.85, refer Rowe 1969), and benthic microalgal production were summarized in Table 5. For the convenient of comparison, the values were unified to the unit of mg C m^{-2} d^{-1}. Carbon supply has been estimated from two different ways: 1) surface productivity measurement and 2) sediment trap deployment. Estimation for the carbon demand has been made from benthic oxygen respiration rates.

Primary production measured in the surface waters ranged from 5.76 to 76.54 mg C m^{-3} d^{-1} (mean value = ca. 41 mg C m^{-3} d^{-1}). Consequently, the vertical flux of organic particles into the benthic community was also low (estimated to vary from 55 to 166 mg C m^{-2} d^{-1}, mean value = 110 mg C m^{-2} d^{-1}). However, benthic community oxygen consumption rate directly measured at the Chamber Site showed relatively high oxygen consumption rate (400 to 800 mg O_2 m^{-2} d^{-1}), which is equivalent to organic carbon demand of 127.5 to 255.0 mg C m^{-2} d^{-1} (mean value = 190 mg C m^{-2} d^{-1}). Benthic microalgae, on the other hand, showed high primary production even under 1% light condition (ca. 180 mg C m^{-2} d^{-1}) during the benthic *in situ* experimental period.

Carbon mass balance was constructed based on the above results in Table 5. The benthic carbon demand estimated from benthic oxygen respiration (190 mg C m^{-2} d^{-1}) far exceeded the input flux of organic particles estimated from sediment trap deployment (110 mg C m^{-2} d^{-1}). The deficit between the supply and the demand of organic carbons was about 80 mg C m^{-2} d^{-1}. One of candidates for additional benthic organic carbon supply to compensate the deficit is benthic microalgal production, which showed high primary production under 1% light condition during the study period.

Our results showed that organic particles supplied from the water colum alone could not sustain the organic demand of the benthic community at the Chamber Site. The discrepancy between surface carbon supply and benthic carbon demand at the Chamber Site suggests that there must be another organic source for the benthic community of the Marian Cove. High primary production of the benthic microalgae, though it was measured in lab condition, implies that benthic microalgal production could be an important organic carbon source for the benthic community. Consequently, the benthic microalgal production is responsible for the high benthic respiration rate and high benthic biomass of the Marian Cove, King George Island, Antarctica at least during the 94/95 austral summer (Fig. 5).

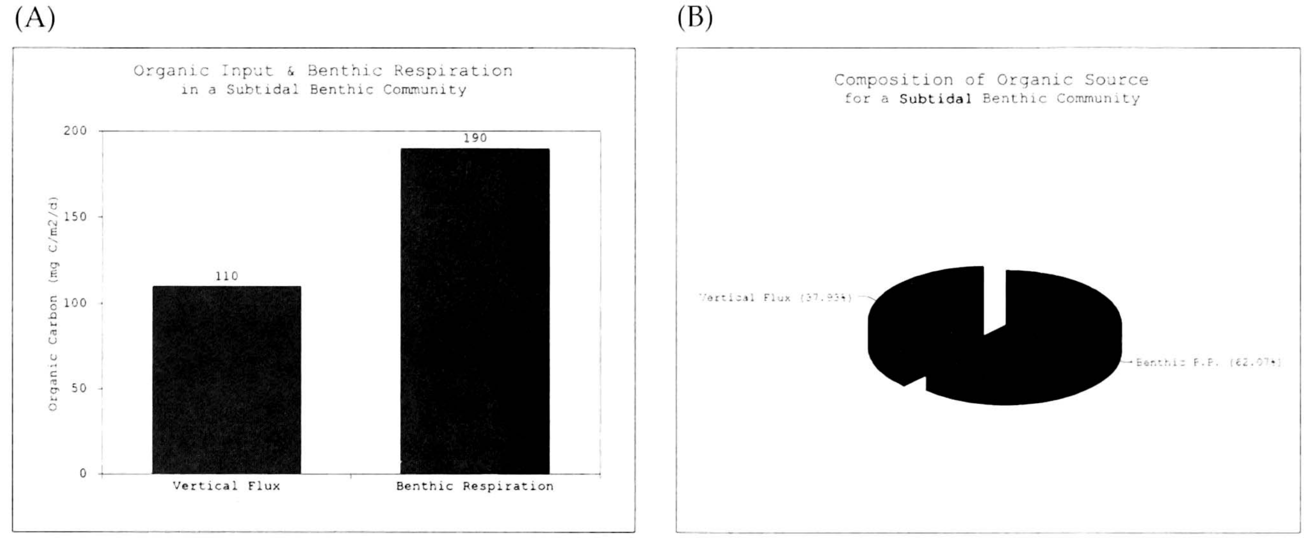


Fig. 5. (A) Unbalance of organic budget between benthic demand and the supply from the overlying water-column at the Chamber Site during the 94/95 austral summer. Organic carbons supplied from water-column alone could not sustain the high benthic demand at the Chamber Site at least during the study period. (B) Composition of organic sources for the benthic community at the Chamber Site. Benthic microalgal production could be a candidate for additional benthic organic supply to compensate the deficit.

Table 5. Organic carbon mass balance in terms of carbon supply and demand at the Chamber Site. Estimation for the carbon supply has been made from two different ways: 1) surface productivity measurement and 2) sediment trap deployment. Estimation for the carbon demand has been made from benthic oxygen respiration rates. The unit is mg C m^{-2} d^{-1}. Values are mean (values in parenthesis are min. and max)

Water-column supply	
(1) Surface production*	41 (5.76 - 76.54)
(2) Particle settling	110 (55 - 166)
Benthic demand (estimated)	
(3) from benthic respirations	190 (127.5 - 255)
Carbon mass balance (deficit)	
(3) - (2)	80
Candidate for additional benthic organic supply to meet the deficit	
(4) Benthic microalgal production	180

*unit = mg C m^{-3} d^{-1}

Conclusion

The benthic community respiration rate directly measured at the Chamber Site was high in spite of low primary production in the surface waters and low organic flux into the benthic community. The benthic microalgae from the Chamber Site showed high primary productivity under 1% light condition, which was similar to the light intensity of the Chamber Site. Consequently, it is suggested that the organic matters supplied from the surface waters could not sustain the high benthic organic demand at the Chamber Site, and the high benthic microalgal production might be an important organic source for the benthic community of the Marian Cove, King George Island, Antarctica at least during 94/95 austral summer.

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