IMPORTANCE OF COASTAL MUDFLAT ECOSYSTEMS IN SOUTH KOREA: STABLE ISOTOPE ANALYSES OF COASTAL BAY FOOD WEBS

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Introduction

The Yellow Sea region includes extensive tidal flats due to the tidal range of more than 4 meters: along the west and south coast of South Korea, a total of tidal flat areas comprise about 2,900 km^2. In some cases they occupy up to 20 km between the tidemarks. In general, tidal flats are subject to physically extreme environmental variability. However, the flats have been claimed to be amongst the most productive natural ecosystems because of a rich food supply from the adjacent sea or land as well as from more numerous primary producers in the flats themselves, compared to the sea. The various food sources result in higher biodiversity and more complex food web. This maintains also a high biomass and production of invertebrates through the steps of food chain. The high biomass of invertebrates then attracts fishes and birds to the tidal flats (reviews in Reise, 1985; McLusky, 1989). Such a general scheme in the tidal flats has been well established in the Korean coast (see Koh, 2001).

Up to now, 40% of the total flat area of South Korea has disappeared by reclamation for Land Development and the reclamation projects still remain under the National Plan. A conflict between reclamation and conservation of the tidal flats has been therefore issued. However, the effect of these anthropogenic activities on bay ecosystems is unknown. Characterisation of trophic base of these coastal communities should provide a baseline for impacts of future utilisation of tidal flats. If intertidally-produced benthic autotrophs play an important role as diet source for consumers in the systems, the extensive disturbance of tidal flats may change the balance of organic matter sources and the food availability in the ecosystems. In order to make intelligent decisions about future proper management of bare intertidal flats, it is essential to understand the flow of energy through food webs and thereby to assess the importance of locally-produced benthic autotrophs as consumer diet in coastal food webs. Information on the roles of potential food sources is still insufficient to establish the trophic base of these ecosystems in Korea because different bay systems have different hydrologic conditions, vegetal and sedimentary composition. In the recent survey, we analysed dual stable isotopes of C and N to characterise the food base for consumers in several coastal bay systems.

This research was aimed to identify organic matter sources that support consumer production within different coastal bay ecosystems of Korea. Since $\delta^{13}C$ signature of benthic microalgae are readily distinguishable and less negative compared with those of salt marsh, terrestrial vascular plants and phytoplankton (Currin et al., 1995; Riera et al., 1999; Maksymowska 2000), and also isotopic signatures of a consumer reflect its diet (DeNiro and Epstein, 1978; Fry and Sherr, 1984), we expected that isotopic signatures of consumers in benthic microalgae-based food webs are less negative than those in marine phytoplankton- or other vegetation-based food webs.

Sampling sites

Sampling sites selected were devided into four types of:

1) the Youngil Bay system, an estuarine bay without any tidal flat, identifying the site as having potential importance of terrestrial and marine particulate matter sources.
2) the Kwangyang Bay system, an estuarine with large and bare intertidal beds. The upper estuarine supralittoral area of the bay is lined with the reed grass *Phragmites communis* communities. Although most of the dense *Zostera* bed which was developed in the whole bay disappeared recently, a part of the bed still exists along the lower intertidal flat boundary. A few macroalgal mats were also found on the tidal flats.
3) the Yoja Bay and Deukryang Bays, free from river discharge with extensive intertidal beds. In Yoja Bay, the upper part of intertidal bed is covered by broad (~10 km^2) marsh plains of *Phragmites communis*. In Deukryang Bay, little marsh grass and macroalgal mats was found and surface sediments are a deposit of suspended sediment from offshore area and nutrients are mainly supplied by the inflow of offshore coastal waters (Kong and Lee, 1994; Yang et al., 1995).
4) the adjacent offshore area around Geomoondo Island, identifying the site as being potentially phytoplankton-based ecosystem.

   In total, 21 sites (7 intertidal, 10 sbutidal and 4 offshore sites) were surveyed on the southern coast of Korea.

Materials and methods

Samples of potential food sources [particulate and sedimentary organic matter (POM and SOM), and primary producers] and consumers were collected during April-July 1999 in Youngil Bay, in November 1999 and May 2000 in Kwangyang Bay, and during May-July 2001 in Kwangyang, Yoja and Deukryang Bays and the offshore area around Geomoondo Island.

Potential food sources for stable isotope analyses contain riverine, coastal and oceanic POM, marsh plants, macroalgae, benthic microalgae, phytoplankton, and seagrass (*Zostera marina*) etc. Various meio- and macro-consumers including pelagic zooplankton, benthic meiofauna, crustaceans, bivalves, gastropods, cephalopods, ascidians, echinoderms, polychaetes and a variety of fish species) were collected by hand or using by extracting methods, dredges, seines, trawls and gill nets etc.

Carbon isotope ratio was determined on a Micromass Prism II isotope ratio mass spectrometer for April-July (1999) samples, a PDZ Europa single inlet dual-collector mass spectrometer for November (1999) and May (2000) samples, a continuous-flow isotope mass spectrometry for May-July (2001) samples, respectively. Nitrogen stable isotope ratio was analysed in the latter two cases. Dried samples (about 1 mg for animal tissues and 5 mg for plant tissues) were combusted in an elemental analyzer and resultant gas (CO_2 and N_2) was introduced to an isotope ratio mass spectrometer in a continuous flow using a He carrier. Data were expressed as the relative per mil (‰) difference between sample and conventional standards of Pee Dee Belemnite carbonate (PDB) for carbon and air N_2 for nitrogen according to the following equation:

$$\delta X = [(R_{sample}/R_{standard}) - 1] \times 10^3$$

where X is ^{13}C or ^{15}N and R is $^{13}C/^{12}C$ or $^{15}N/^{14}N$. Secondary standard of known relation to the international standard was used as a reference material. The standard deviations of $\delta^{13}C$ and $\delta^{15}N$ for 20 replicate analyses of the internal peptone standard were ± 0.1 and ± 0.2, respectively.

Results

Isotopic composition of potential resources

Stable carbon isotope ratios for primary producers (i.e. marsh grass, phytoplankton, seagrass, benthic micro- and macroalgae, and riverine POM) from the south coast of Korean varied with a relatively wide range between –29.9 and –8.8‰ (Table 1), showing a substantial variation among plant taxa (Duncan multiple comparison test, $P<0.05$). Accordingly, most the plant groups were easily differentiated by their carbon isotopic composition. Despite a narrower range (6.1 to 14.8‰) relative to that of $\delta^{13}C$ values, their mean $\delta^{15}N$ values tended to be separated distinctly into three different groups, i.e. riverine POM–marsh grass, phytoplankton–benthic diatom and macroalgae–*Zostera* (Duncan multiple comparison test, $P<0.05$). Although benthic diatom and macroalgae were overlapped in the ranges of their $\delta^{13}C$ values, macroalgae had heavier $\delta^{15}N$ values and thus dual isotope plot of $\delta^{13}C$ and $\delta^{15}N$ distinguished more clearly primary producers. There were little great systematic variations among coastal sites in $\delta^{13}C$ and $\delta^{15}N$ values for the same plant taxa (ANOVA, $P>0.1$ for both $\delta^{13}C$ and $\delta^{15}N$ values of *Phragmites*, phytoplankton and benthic diatom).

Table 1. Stable isotope ratio (‰) of suspended particulate organic matter (POM), primary producers and sedimentary organic matter (SOM) collected from the southern coastal bay and offshore systems of Korea

Group	$\delta^{13}C$	$\delta^{15}N$
Terrestrial		
Riverine POM	–29.9 to –23.7	8.6*
Marsh plants *Salix gracilistyla*	–27.8 to –26.1	8.0*
Saltmarsh *Phragmites communis*	–28.9 to –25.5	6.1 to 8.6*
Algae		
POM	–20.2 to –18.6	8.8 to 11.8
Phytoplankton	–21.6 to –19.6	9.5 to 11.7
Benthic diatom (benthic microalgae)	–14.9 to –13.7	10.8 to 11.0
Macroalgae	–16.5 to –13.7	11.0 to 14.8
Seagrass *Zostera marina*	–11.5 to –8.8	14.1
SOM	–19.6	10.4

Isotopic composition of consumers

Percentage frequency distribution of $\delta^{13}C$ values of consumers in the study areas revealed a separation in carbon flow between those from the Youngil Bay and offshore systems, and the Kwangyang, Yoja and Deukryang Bay systems. Consumers from the former systems had more negative $\delta^{13}C$ signatures relative to ones from the latter systems, indicating the formers' dependence on marine phytoplankton (and/or POM) as their food base. These results also indicate the higher contribution of marine benthic autotrophs as food source for the latter consumers.

Considering the biomasses of marine benthic autotrophs and trophic fractionation of 3-4‰ in nitrogen isotope values per trophic level (Deniro and Epstein, 1981; Minagawa and Wada, 1984), benthic microalgae is most probable source that can be responsible for the more positive $\delta^{13}C$

distribution of the latter consumers. The dashed lines indicate the expected trophic enrichment effect in C and N isotopic signatures through the offshore phytoplankton-based food web (Fig. 2). Had consumers within the bay systems been relying on macroalgae, one would have expected to have primary consumer $\delta^{15}N$ between 15 and 19‰. Instead, there was an overlap in the $\delta^{15}N$ signatures between macroalgae and primary consumers, indicating little contribution of macroalgal diet source for the consumers. With the exception of a few area of *Zostera* bed in the Kwangyang Bay system, Yoja and Deukryang Bays were free from *Zostera*.

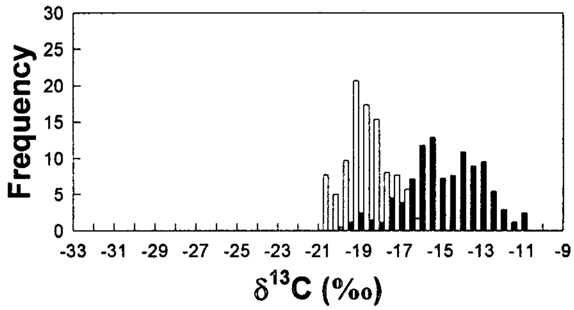

Fig. 1. Comparison between $\delta^{13}C$ distri-butions of consumers from the Youngil Bay (white bars) and offshore systems and the Kwang-yang, Yoja and Deukryang Bay systems (black bars).

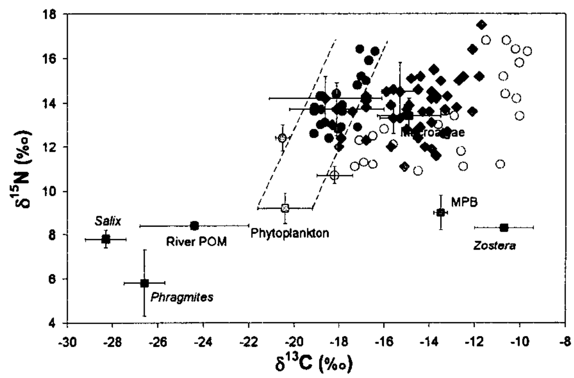

Fig. 2. Scatter plot of $\delta^{13}C$ versus $\delta^{15}N$ signatures (‰) of consumers in the Kwangyang Bay and offshore systems (data from the survey of 1999): ● offshore, ◆ subtidal and o intertidal consumers.

Significance of the results

The significance of the results from this research includes:

1) Dominant benthic vegetations were isotopically well distinguished from riverine and marine POM, marsh plants and phytoplankton.

2) The $\delta^{13}C$ signatures of consumers were spanned in a narrower range relative to those of potential food resources, showing a great resemblance for the same species among the systems. These consumer isotopic ratios strongly suggested the assimilation of the relatively positive carbon sources (phytoplankton and marine benthic vegetation).

3) The $\delta^{13}C$ signatures of consumers within the coastal bay systems with large and bare were quite different from those for the offshore phytoplankton-based ecosystem, particularly in the ^{13}C enrichment of benthic grazers, deposit-feeders and benthic feeders of fishes. This tendency of the ^{13}C enrichment was also found in suspension-feeding bivalves. Taking the biomasses of benthic vegetation into consideration, benthic microalgae was likely to account for the consumer ^{13}C enrichment. Also, within the former systems, the $\delta^{13}C$ values of pelagic consumers (e.g. pelagic copepods, suspension-feeders and planktivorous fishes) reflected a greater dependence on phytoplankton than those of benthic consumers (e.g. benthic copepods, deposit-feeders and benthic feeders of fishes), which were closer to benthic vegetation. The isotopic difference between pelagic and benthic consumers indicated that the carbon derived from intertidal benthic vegetation might be incorporated to food webs mostly through benthic food chains.

4) Role of riverine terrestrially derived POM was limited to the riverine system and was not evident from the estuary to the bay channel systems.

Future Research

Future research initiatives, expending on complementary isotopic studies of ineraspecific or seasonal variation at the west coast of Korea might yield interesting insights into roles of benthic microalagal production on the tidal flats.

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