Filtration, Respiration and Assimilation in the Suspension Feeding Bivalves, *Limnoperna fortunei kikuchii* and *Mactra veneriformis*

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**ABSTRACT**

The filtration, respiration and assimilation rates in the suspension feeding bivalves, *Limnoperna fortunei kikuchii* and *Mactra veneriformis* were examined.

The results can be summarized as follows: 1) Filtration and respiration rates per unit wet tissue weight of both *L. f. kikuchii* and *M. veneriformis* increased in accordance with increase in water temperature and decrease in the shell-length. These values increased in growth phase. 2) Differences in the circumstances of bivalves habitat, such as intertidal and undertidal zones affected the daily changes of the filtration and feces excretion rates. 3) The filtration and respiration rates of both bivalves were expressed by the following Equations:

- **Limnoperna fortunei kikuchii**
  \[
  F (\text{ml} \cdot \text{g}^{-1} \cdot \text{hr}^{-1}) = 7.8 \times 10^{-3} \times t^{2.33} \times W^{-1.19} \quad (r^2 = 0.97, n = 16, \text{wet tissue weight} \ 0.144-0.356 \ \text{g and 10-28 °C in water temperature})
  \\
  R (\text{mg} \cdot \text{O}_2 \cdot \text{g}^{-1} \cdot \text{hr}^{-1}) = 7.8 \times 10^{-6} \times t^{3.01} \times W^{-0.29} \quad (r^2 = 0.98, n = 17, \text{wet tissue weight} \ 0.151-0.478 \ \text{g and 10-28 °C in water temperature})
  \]

- **Mactra veneriformis**
  \[
  F (\text{ml} \cdot \text{g}^{-1} \cdot \text{hr}^{-1}) = 4.9 \times 10^{-1} \times t^{0.77} \times W^{-0.90} \quad (r^2 = 0.94, n = 16, \text{wet tissue weight} \ 0.237-3.488 \ \text{g and 10-28 °C in water temperature})
  \\
  R (\text{mg} \cdot \text{O}_2 \cdot \text{g}^{-1} \cdot \text{hr}^{-1}) = 5.0 \times 10^{-4} \times t^{1.63} \times W^{-1.29} \quad (r^2 = 0.99 \quad \text{and} \quad n = 16, \text{wet tissue weight} \ 0.237-3.488 \ \text{g and 10-28 °C in water temperature})
  \]

4) Assimilation rate of both bivalves decreased with the increase of shell-length and the decrease of water temperature. *M. veneriformis* generally had a higher assimilation rate than *L. f. kikuchii*.

**Key words:** filtration, respiration, assimilation, *Limnoperna fortunei kikuchii,* *Mactra veneriformis*
INTRODUCTION

*Mytilus edulis*, *Crassostrea gigas*, and *Limnoperna fortunei kikuchii* are typical sessile animals which settled the revetment of Tokyo Bay.

The sessile animals of the inner part of Tokyo Bay weigh about 9,110 t at a revetment distance of 192 km and revetment areas of about 33,000 m² (upper tidal zone~sea bottom) during a year¹).

*L. f. kikuchii* accounts for about 20 % of the total number of these animals and therefore plays an important role in forming the coastal ecosystem. *L. f. kikuchii* does not form a water pipe, has a shell that opens partway, and filters suspension solids in water. The origin of this bivalve is China and Taiwan, however, it is widely distributed on the shores of the Pacific Ocean, from the inner part of Seto Bay, Urato Bay (Kouchi Pref.) to Tokyo Bay, and in the Sea of Japan, from Doukai Bay (Fukuoka Pref.) to Shinji Lake (Shimane Pref.). This bivalve can live in an inner bay area, the mouth of a river, an inland sea and brackish water due to a high level of salinity tolerance²,³).

On the other hand, *Mactra veneriformis* is a typical bivalve that lives in the shoal of Tokyo Bay, and the environment it lives in is similar to that of *Tapes japonica*. *Mactra veneriformis* forms a water pipe, takes in sea water from it, and filters suspension solids in its mantle cavity.

It is widely distributed from south of Miyagi Pref. to Kyushu of the southern part of Enkaisyu in Japan, the Korean peninsula and the Chinese coast⁴).

This bivalve lives for two or three years. It filters polluted matter (organic matter) in the process of feeding and growth.

Recently, many researcheres have much attention to the purification of suspended organic matter by bivalves. Then, researches have been done on the purification ability of bivalves, which has focused on *Mytilus edulis*, *Crassostrea gigas*, *Tapes japonica*, *Mactra chinensis*, *Musculus senhousia*, *Meretrix lusoria* and *Pseudocardium sachalinense*, etc⁵–⁷, ¹⁶–¹⁹).

However, little is known of the purification abilities about *L. f. kikuchii* and *M. veneriformis*. The authors examined the effects of water temperature and shell-length (wet tissue weight) on the filtration, respiration, egesta and assimilation rates in regard to *L. f. kikuchii* and *M. veneriformis* which are predominant in the revetment and the shoal in the inner part of Tokyo Bay.

MATERIALS AND METHODS

The experiments for the measurement of filtration, respiration and excretion rates were done with water temperatures of 10, 20, 28 ºC, and those of feces and pseudofeces excretion rates were done with water temperature of 20 ºC. The bivalves were collected from the inner part of Tokyo Bay when the water temperature was the same as the water temperature used in the experiment. The sea water was taken from the same place, and used after filtrating with GFC filter paper. The following bivalves were used in this experiment: *Limnoperna fortunei kikuchii* with a large shell-length of 27.4–33.0 mm (wet tissue weight 0.31–0.36 g), a middle one of 21.7–26.3 mm (0.26–0.30 g), and a small one of 15.0–20.4 mm (0.14–0.22 g), as well as *Mactra veneriformis* with a large shell-length of 36.2–42.9 mm (wet tissue weight 2.23–3.49 g), a middle one of 27.2–33.9 mm (1.10–1.62 g), and a small one of 18.0–23.5 mm (0.24–0.64 g). Each experiment group was combined in parallel with 2 groups that were under the same conditions; in addition, there was a control system with no bivalves. Filtration rate was measured as follows: A glass container (3 l) was filled with 2.0–2.6 l of...
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filtered sea water, and had cultured phytoplankton (green algae of diameter about 2.5 μm) put into it. COD of the experimental sea waters was also adjusted ranging from 4 to 8 mg·l⁻¹; next, bivalves were placed in it (L. f. kikuchii 20 pieces, M. veneriformis 4-8 pieces), and the filtration rate was obtained by the Equations (1) and (2) using the difference in the concentration of COD before and after a given period of time (L. f. kikuchii 1-5 hr, M. veneriformis 0.75-0.83 hr) when the bivalves were stabilizing (L. f. kikuchii: when filtration is started on the net as the substrate, M. veneriformis: when its tube appeared from the glass beads with 0.5~1.0 mm in diameter which were substitutes for sand).

\[ S_t = S_0 \cdot e^{(-rt)} \]  
\[ F = (V \cdot r) \cdot B^{-1} \]

Where \( S_t \) is the suspended COD (mg·l⁻¹) at time \( t \), \( S_0 \) is the initial suspended COD (mg·l⁻¹), \( r \) is a constant representing the COD removal rate (hr⁻¹) and \( t \) is the experimental time(hr). Then, filtration rate is expressed by Equation (2).

Where \( F \) is the filtration rate per unit wet tissue weight (ml·g⁻¹·hr⁻¹), \( V \) is the experimental volume of sea water(l), and \( B \) is the total wet tissue weight of experimental bivalves(g).

Respiration rate (R) and urine and mucus excretion rate (U) were obtained as follows: a glass container was filled with 500 ml of filtered sea water after it had been aerated for a few minutes; then, the experimental bivalves (L. f. kikuchii 5 pieces, M. veneriformis 4-8 pieces) were placed into the container and it was sealed. Respiration and excretion rates were obtained from the differences in the DO and COD before and after a fixed time (2-6 hr), respectively.

Feces and pseudofeces excretion rates (FE) were estimated as follows: the experimental sea water was injected continuously with the flow rate of 100 ml·min⁻¹ into the water tank (L35×W35×H15 cm) where bivalves had been placed (L. f. kikuchii 10 pieces, M. veneriformis 8-12 pieces), and feces and pseudofeces were collected once per hour over a 7-8 hours period when the bivalves were stabilized. The feces excretion rate per wet tissue weight was estimated from the total amounts of feces and pseudofeces in that period.

Assimilation rate (A) was obtained from the subtraction of the sum of feces and pseudofeces, and urine and mucus excretion rates from food consumed rate (C). The Equation for C was:

\[ C = (S_0 \cdot V \cdot r) \cdot B^{-1} \]

Where C is the food consumed rate based on COD (mg·g⁻¹·hr⁻¹).

Then, assimilation rate can be calculated as:

\[ A = (C - (FE + U)) \]

However, the amount of COD excretion was negligible, so U was disregarded.

RESULTS AND DISCUSSION

Filtration Rate Filtration rate of L. f. kikuchii and M. veneriformis decreased in accordance with an increase in the shell length (Fig. 1). This tendency was confirmed in Tapes japonica5) and Macoma masuta, Mytilus californianus, Chlamys hastata8), Crassostrea virginica, Geukensia demissa and Mercenaria mercenaria9). The filtration rate of L. f. kikuchii in a large shell-length decreased to 38 % of that in a small shell-length at 10 °C, 25 % at 20 °C and 88 % at 28 °C. The difference of filtration rate by shell-length was small in high temperature. It is considered that the high activity of L. f. kikuchii occurs under environmental conditions of comparatively high water temperatures. On the other hand, the filtration rate of M. veneriformis in a large shell-length decreases to 9 % of that in a
small shell-length at 10 °C, 12 % at 20 °C and 12 % at 28 °C.

The decrease of filtration rate with the increase of shell-length is more significant in L. f. kikuchii, comparing with that in M. veneriformis.

The filtration rates of small shell-length bivalves for each temperature were 14.6, 94.8, 120 ml·g⁻¹·hr⁻¹ in L. f. kikuchii, and 78.9, 138, 193 ml·g⁻¹·hr⁻¹ in M. veneriformis at water temperatures of 10, 20, 28 °C, respectively. The filtration rate of M. veneriformis at 20 °C was 1.7 times as large as that at 10 °C and it was 6.4 times for L. f. kikuchii.

The filtration rate was strongly affected by water temperature, and it is thought that a low water temperature is a bigger stress for L. f. kikuchii, though M. veneriformis tolerate low water temperatures. Akiyama showed that a value of about 2.8 times which uses Tapes japonica (shell-length 33–38 mm) and a value of about 2.1 times with Musculus senhousia (shell-length 14–15 mm). This tendency was also found in middle and large shell-lengths. The filtration rates of 28 °C to 20 °C were 1.2~4.3 times in L. f. kikuchii, and 1.4~1.6 times in M. veneriformis, respectively. These differences are smaller than the value of 20 °C to 10 °C, however,
the filtration rate increased and the increase in efficiency was higher in \textit{L. f. kikuchii} than in \textit{M. veneriformis}. Experimental data for the other suspension feeding bivalves was 300–700 ml·g$^{-1}$·hr$^{-1}$ at 18–20 °C in \textit{Venus mercenaria}\textsuperscript{10}, 900 ml·g$^{-1}$·hr$^{-1}$ at 9.7–10.1 °C in \textit{Cardium edule}\textsuperscript{11}, 400–500 ml·g$^{-1}$·hr$^{-1}$ at 12.5–13.0 °C in \textit{Clinocardium muttallii}\textsuperscript{12}, 1000 ml·g$^{-1}$·hr$^{-1}$ at 12.5–13.0 °C in \textit{Mytilus californianus}\textsuperscript{12}, 1400–1600 ml·g$^{-1}$·hr$^{-1}$ at 12.5–13.0 °C in \textit{Chlamys hastata}\textsuperscript{12}. Though, the filtration rate is varied with the bivalves's size and depending on factors like the concentration and size of food, the water temperature, and the experimental methods, we found that the filtration rates of \textit{L. f. kikuchii} and \textit{M. veneriformis} were generally small compared to those of bivalves like \textit{Venus mercenaria}\textsuperscript{10}.

**Respiration Rate** The respiration rate of \textit{L. f. kikuchii} and \textit{M. veneriformis} increased in order of a shell-length of small $>$ middle $>$ large; the respiration rate increased more in the small bivalves in the growth phase (Fig. 2). This tendency was confirmed for \textit{Spisula sachalinensis}, \textit{Mactra chinensis}, \textit{Gomphina melanaegis}, \textit{Peronidia venulosa}\textsuperscript{13}, \textit{Choromytilus meridionalis}\textsuperscript{14} and \textit{Cardium}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2}
\caption{Relationship between filtration rate and water temperature for shell-length.}
\end{figure}
As compared with a small shell-length in regard to the effects of water temperature, the respiration rates of *L. f. kikuchii* at 20 ºC was about 6 times as large as that at 10 ºC, and that at 28 ºC was 15 times to that at 10 ºC and about 2.4 times to that at 20 ºC. On the other hand, the respiration rates of *M. veneriformis* at 20 ºC were about 10 times to that at 10 ºC, and that at 28 ºC was 15 times to that at 10 ºC and 1.4 times to that at 20 ºC.

The differences in respiration rate by shell-length were small for all experimental temperatures in *L. f. kikuchii*, however, the respiration rate of *M. veneriformis* was significantly different between small, middle and large shell-lengths at relatively high temperatures 20 and 28 ºC.

The respiration rate of *M. veneriformis* may significantly decreases in an environment with high water temperature, especially in grown-up shell. Researchers have found that *M. chinensis* with shell-length of 15-30mm that are part of the same family as *M. veneriformis* had a respiration rate of about 1.6 times of 22 or 24 ºC against 17 ºC in water temperature. Here, since there is a relationship between the wet tissue weight of individual and the ratio of filtration rate to respiration rate for water temperature of 10–28 ºC (Fig. 3). The ratio of *L. f. kikuchii* decreases rapidly with the increase in individual wet tissue weight at 20 and 28 ºC in particular. On the other hand, that of *M. veneriformis* increases when the individual wet tissue weight increases until 1 g. However, after that, even if the individual wet tissue weight increases, it tended to decrease or level-off. This shows that the amount of energy consumption for growth and reproduction decreases with growing of shell-body.

*M. veneriformis* uses an almost fixed rate of energy for growth, reproduction, and life-support although it matures when the individual wet tissue weight exceeds about 1g; in addition, it is known that *L. f. kikuchii* grows fast; however, when the individual wet tissue weight increases to about 0.3 g, much of the energy intake is used for life-support.

**Daily Changes of Filtration, Respiration, and Feces and Pseudofeces Excretion Rate** Figure 4 showed the filtration and respiration rates of *L. f. kikuchii* which were measured four times a day with water temperature of 20 ºC. They changed primarily due to time and feeding action was not always shown. In particular, because *L. f. kikuchii* is located in the upper part of the intertidal zone and feeding action may be interrupted compulsorily because of a lack of water during low water. The feeding pattern which was applied to these environments was repeated in this experiment without changing of water level. Then, the feces and pseudofeces excretion rates in a 24 hour period was examined every two hours (Fig. 5). Changes in the feces excretion rate were large, and the time zone in which feces and pseudofeces were barely excreted was seen at 2 p.m to 4 p.m. However, the other time zone did not show a clear tendency in feces and pseudofeces excretion. In regard to feces excretion, it tended to increase and decrease every six hours; this was similar to the ebb and flow cycle. On the other hand, the pseudofeces excretion rate was high from 4 p.m to 6 p.m and from 2 a.m to 4 a.m when the feces excretion rate approached 0. However, the relationship between the pseudofeces excretion rate, the egesta rate, which is the sum of feces and pseudofeces, and the tide was not clear. Studies did not find clear evidence about the relationship between the filtration rate and the tide in *Mytilus edulis* and *Choromytilus meridionalis*. However, Griffiths (1980)
studied the filtration rate every two hours for *Choromytilus meridionalis* which inhabits the intertidal and undertidal zones. He found that the bivalves that inhabit the intertidal zone have a higher filtration rate than those in the undertidal zone. There is the possibility that the egesta rate is affected by the tide from the actual experiment results.

The peak amount of feces appeared at an interval of 2–3 hours. It was estimated that the "feeding → food to digestion tube → feces excretion amount increase → satiation → short passing of digestion tube → pseudofeces excretion amount increase → hunger → food to digestion tube" cycle was done at intervals at this time. These changes
Fig. 4 Temporal changes in the filtration and respiration rates of *Limnoperna fortunei kikuchii* (20 °C).

![Graph showing filtration rate and respiration rate over time](image)

Fig. 5 Temporal changes in the egesta rate, feces and pseudofeces excretion rates of *Limnoperna fortunei kikuchii* (20 °C).

![Graph showing egesta, feces, pseudofeces over time](image)

are thought to be related to digestive gland activity\(^{14}\). *Mytilus edulis*, which inhabits a lower zone than *L. f. kikuchii*, does not clearly show a relationship between feces excretion rate and the tide (Kimura, unpublished data). The peak of the total amount of feces is a long cycle that occurs about two times per day; the feces excretion rate does not approach 0 and filtering is stable. These long-cycle changes are usually associated with tidal exposure\(^{17,18}\).

The time changes in the filtration rate of
M. veneriformis are small compared with those of L. f. kikuchii. It is stable in a one day period (Fig. 6). This may have caused the differences in the environment which L. f. kikuchii lives in the upper part of the intertidal zone; in addition, M. veneriformis is always exposed to the tide. The respiration rate of both bivalves did not change significantly, and they respired stably. In an experiment in a 24 hour period, the feces excretion rate of M. veneriformis changed, but it was more stable than L. f. kikuchii (Fig. 7).

M. veneriformis put out a negligible amount of fake feces and excrete feces through digestion. Active feeding was observed in M. veneriformis from 4 p.m to 4 a.m, the feces excretion rate increased.

Fig. 6 Temporal changes in the filtration and respiration rates of Mactra veneriformis (20°C).

Fig. 7 Temporal changes in the egesta rate, feces and pseudofeces excretion rates of Mactra veneriformis (20°C).
However, the feces excretion rate from 8 a.m to 2 p.m decreased slightly and activity was comparatively slack. This does not mean that the bivalves are always feeding actively.

The filtration and respiration rates are shown by the next expressions, which is a function of bivalves' wet tissue weight and the water temperatures.

- *Limnoperna fortunei kikuchii*

  \[ F \left( ml \cdot g^{-1} \cdot hr^{-1} \right) = 7.8 \times 10^{-3} \times t^{2.33} \times W^{-1.19} \quad (r^2 = 0.97, n = 16, \text{ wet tissue weight} \ 0.144-0.356 \ g \text{ and } 10-28 \ ^\circ C \text{ in water temperature}) \]

  \[ R \left( mg \cdot O_2 \cdot g^{-1} \cdot hr^{-1} \right) = 7.8 \times 10^{-6} \times t^{3.01} \times W^{-0.29} \quad (r^2 = 0.98, n = 17, \text{ wet tissue weight} \ 0.151-0.478 \ g \text{ and } 10-28 \ ^\circ C \text{ in water temperature}) \]

- *Mactra veneriformis*

  \[ F \left( ml \cdot g^{-1} \cdot hr^{-1} \right) = 4.9 \times t^{0.77} \times W^{-0.90} \quad (r^2 = 0.94, \ n = 16, \text{ wet tissue weight} \ 0.237-3.488 \ g \text{ and } 10-28 \ ^\circ C \text{ in water temperature}) \]

  \[ R \left( mg \cdot O_2 \cdot g^{-1} \cdot hr^{-1} \right) = 5.0 \times 10^{-4} \times t^{1.63} \times W^{-1.29} \quad (r^2 = 0.99, \ n = 16, \text{ wet tissue weight} \ 0.237-3.488 \ g \text{ and } 10-28 \ ^\circ C \text{ in water temperature}) \]

Assimilation Rate Assimilation rates (which was based on COD) of *L. f. kikuchii* and *M. veneriformis* rose in accordance with shell-length: small > middle > large (Fig. 8). In the small shell-length, assimilation rate rose rapidly when water temperatures increased. However, the effects of temperature became small with growth. In particular, this tendency was significant in *M. veneriformis*. There was a decreasing tendency for the assimilation rate in accordance with growth. In bivalves with a large shell-length (which were assumed to be

![Fig. 8 Relationship between assimilation rate and shell-length for water temperature.](image-url)
adult bivalves), the assimilation rate primarily was used to metabolize energy rather than for growth. This is thought to lower the assimilation rate\textsuperscript{10}. The average assimilation rate for each shell-length of \textit{L. f. kikuchii} were 24% at 10 °C, 30% at 20 °C, and 46% at 28 °C. On the other hand, the value of \textit{M. veneriformis} was 43% at 10 °C, 59% at 20 °C, and 60% at 28 °C.

The assimilation efficiency per wet tissue weight 1 g of \textit{M. veneriformis} was larger than that of \textit{L. f. kikuchii}, and \textit{M. veneriformis} assimilates more efficiently than \textit{L. f. kikuchii}. The assimilation rate of \textit{L. f. kikuchii} was 0.02 mg·g$^{-1}$·hr$^{-1}$ at 10 °C, 0.14 mg·g$^{-1}$·hr$^{-1}$ at 20 °C, 0.42 mg·g$^{-1}$·hr$^{-1}$ at 28 °C, and the assimilation rate of \textit{M. veneriformis} was 0.15 mg·g$^{-1}$·hr$^{-1}$ at 10 °C, 0.47 mg·g$^{-1}$·hr$^{-1}$ at 20 °C, 0.77 mg·g$^{-1}$·hr$^{-1}$ at 28 °C. \textit{M. veneriformis} generally had a higher assimilation rate than \textit{L. f. kikuchii}. The assimilation rate changed because of the concentration of food, water temperature, shell-body'size, level of hungry etc. The organic matter assimilation efficiency of suspension feeding bivalve \textit{Ruditapes philippinarum} and \textit{Musculus senhousia} was 34-44% at 20 °C\textsuperscript{5}. These COD assimilation rate values are similar to our results.

**CONCLUSIONS**

The filtration, respiration and assimilation rates of suspension feeding bivalves, \textit{L. f. kikuchii} and \textit{M. veneriformis} were examined. The results can be summarized as follows: 1) Filtration and respiration rates per unit wet tissue weight of both \textit{L. f. kikuchii} and \textit{M. veneriformis} increased in accordance with increase in water temperature and decrease in the shell-length. These values increased in growth phase. In particular, the filtration rate of \textit{L. f. kikuchii} increased significantly at high water temperatures. As for the relationship to respiration rate, \textit{L. f. kikuchii} also tended to demonstrate a high activity at high water temperatures. 2) Differences in the circumstances of bivalves habitat, such as intertidal and undertidal zones affected the daily changes of the filtration and feces excretion rates. Moreover, a relationship between tide and feeding activity was suggested in \textit{L. f. kikuchii}. 3) The filtration and respiration rates of both bivalves were expressed by the following Equations:

- \textit{Limnoperna fortunei kikuchii} $F$ (ml·g$^{-1}$·hr$^{-1}$) = 7.8 × 10$^{-3}$ × t$^{2.33}$ × W$^{-1.19}$ ($r^2 = 0.97$, n = 16, wet tissue weight 0.144-0.356 g and 10-28 °C in water temperature).
- \textit{R} (mg·O$_2$·g$^{-1}$·hr$^{-1}$) = 7.8 × 10$^{-6}$ × t$^{3.01}$ × W$^{-0.29}$ ($r^2 = 0.98$, n = 17, wet tissue weight 0.151-0.478 g and 10-28 °C in water temperature)

- \textit{Mactra veneriformis} $F$ (ml·g$^{-1}$·hr$^{-1}$) = 4.9 × t$^{0.77}$ × W$^{-0.90}$ ($r^2 = 0.94$, n = 16, wet tissue weight 0.237-3.488 g and 10-28 °C in water temperature).
- \textit{R} (mg·O$_2$·g$^{-1}$·hr$^{-1}$) = 5.0 × 10$^{-4}$ × t$^{1.63}$ × W$^{-1.29}$ ($r^2 = 0.99$ and n = 16, wet tissue weight 0.237-3.488 g and 10-28 °C in water temperature)

4) Assimilation rate of both bivalves decreased with the increase of shell-length and the decrease of water temperature. \textit{M. veneriformis} generally had a higher assimilation rate than \textit{L. f. kikuchii}.

**ACKNOWLEDGMENT**

We thank YASUSHI Ichimura (MIKUNIYA CORPORATION) for much valuable aid.

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(Submitted 1998. 3. 16) (Accepted 1998. 5. 19)