Effects of Groins on Habitat Environments and Trophic Relations in River Estuary with References to *Corbicula* Bivalve Populations

by

Nannan LI

Supervised by

Professor Takashi TASHIRO

A thesis submitted in partial fulfillment of the requirements for the degree of
DOCTOR OF ENVIRONMENTAL STUDIES

Nagoya University

2016

ACKNOWLEDGEMENT

I would like to express the deepest appreciation to my supervisor Tashiro Takashi, who taught me professional knowledge every week. I changed my major from agriculture irrigation to civil environment for my Ph.D. Due to I'm not familiar with the major knowledge regarding hydraulic environment science, he always brought some document and discussed with me in order to find the research topics which I am interested in. Prof. Tashiro consistently has a meeting with me every week. Sometimes I could not attend the meeting because of family matter, he would change schedule to make sure our weekly meeting. He always actively helped us to engage in field investigation, even though sometimes sampling collection in the river was dangerous. Without all of the efforts from Prof. Tashiro, it would not have been possible to graduate with doctoral degree.

I am grateful to my committee members, Prof. Y. Toda, Prof. K. Sugitani, and Prof. H. Tanikawa for their thoughtful comments. I was impressed by their attentive reading of my thesis draft and helpful advice. In addition, I am grateful to Profs. Tsujimoto and Obana for their comments and discussions in the laboratory seminars. Also I would like thank to Yoshimoto and Ito, I was impressed by their careful field investigation and their data collection.

Before I started my Ph. D. course, I was a housewife in Japan. I am not adapt to housewife life, because I found this life pattern was too boring and lonely. My husband Zhao Jun greatly supported me to start Ph. D. course in Nagoya University. When I was busy or did feel pressure in doing research, He would comfort me and encouraged me. I will heartily thank to my husband.

Finally, I am very grateful to my mother and mother in law. During Ph. D. course period, I gave birth to two children. It was impossible to take care of baby when I did research. So they came to Japan and took care of my family for 6 months after baby born. And also they will encourage me to finish Ph. D. course and get the degree.

CONTENTS

ABTRACT

Effects of Groins on Habitat Environments and Trophic Relations in River Est uary

with reference to *Corbicula Bivalve* Populations

Groin was a structure extending outward from the bank with functions of deflecting the currents and waves and preventing from its erosion along coasts or rivers. Recently, other ecological functions have also been watched. It has been considered as one of the most effective methods to create diverse landscapes and to restore natural river ecosystem by changing hydrodynamic fields with geomorphic processes. On the other hand, river estuary is one of the most productive fields by providing the material and energy sources from both of the terrestrial and seaward ecosystem where the catches of dominant benthic organism, -*Corbicula* bivalves have been decreased tendency in the last several decades. A lot of groin structures have been installed in estuaries of alluvial rivers in order to protect and sustain adjacent urban and rural human societies. However, few studies have concentrated on *Corbicula* bivalves in the formed diverse landscapes due to the groin installations in the river estuaries. The effect of these diverse landscapes on the bivalves inhabitations should be is treated as a key to be clarified since ecosystem conservation is one of the critical issues in river management and fishery conservation. The primary goal of this study is to investigate the effects of installation of series of groins on distribution of *Corbicula* bivalves and on the variations of their food sources in the diverse landscapes.

In this study, I set Kiso estuary as the target field. It could be described that the

geomorphology, hydraulic feature, salinity intrusion, sediment characteristics are strongly influenced there by the installation of a series of groins. Furthermore, since the environmental conditions are complicated due to the tidal effects in river estuaries and the variables to influence *Corbicula* bivalves have never been described, it is recognized that the effects of environmental factors on their distributions were needed to be quantitatively described. Consequently, I suggested that the present study should be conduct to treat the ecosystem variations in longitudinal and transverse directions along the river with reference to a series of groins.

In order to understand the effect of environment variables caused by groin installations, I designed the sampling locations with and without groins and in multiple cross-sections. Not only water, and substrate conditions of the habitat and diet condition, but also the biomass and densities were investigated and measured in the target locations. Two-way ANOVA test and multiple regression analyses were utilized to check the variations along the longitudinal and transverse directions in all of the environmental variables and these effects on *Corbicula* bivalves. Two-way ANOVA result showed that the installation of groins could promote significant higher water depth and relatively higher salinity conditions, and the substrate conditions with homogeneous distributions in the area with groins. The multiple regression analyses showed that the *Corbicula* biomass and densities could be relatively described with equations included the critical environmental variables, moreover the habitat preferences would be different between two species of *Corbicula*. Hence, it could be suggested that the series of groins conserve not only the adjacent human societies, but also the biomass and densities of *Corbicula* bivalves.

In order to clarify the effects of different landscapes caused by groin installations on *Corbicula* bivalves' food sources variations, potential food sources (suspend particulate organic matters) in upper and lower reaches were collected and were tried to relate to some types of *Corbicula* bivalves with species and size differences. Based on signatures of carbon and nitrogen stable isotope ($\delta^{13}C$ and $\delta^{15}N$), it could be understood that the origins and dispersions of suspend particulate organic matters are relatively different in each of the location. Adopting the "Isosource" mixing model with these signatures, I could evaluate the food sources in each of the landscapes as follows: groin terrain and riparian vegetation probably influence the origin and distribution of suspend particulate organic matters (POMs); *Corbicula japonica* is selective filter feeder, mainly depended on terrestrial POMs; and *Corbicula leana* is opportunistic filter feeder, mainly depended on the suspended POM derived from neighbor water column.

Chapter 1

INTRODUCTION

1.1 Backgrounds

1.1.1 Characteristics in estuary ecosystem

Fluvial ecosystem integrates the community with biological interactions and all of the physical and chemical processes, which collectively determine how systems function (Allan et al., 2008). Fluvial ecosystem is composed of two parts as follows: aquatic biological communities and abiotic environment. Abiotic environment includes hydrological processes (flow, runoff, flood), energy, climate, substrate (sediment, geology and geomorphology) raw materials (inorganic and organic matters). Fish, zooplankton, benthic animals, amphibians, phytoplankton, aquatic plants constitute the aquatic biological communities. Different from other ecosystems, the fluvial ecosystem is especially open exhibiting high connectivity longitudinally, laterally and vertically (Allan et al., 2008). Hence, abiotic environment changed in fluvial ecosystem is likely to have a rapid and significant impact on the composition and structure of biological communities compared with those in other ecosystem.

An estuary is a semi-enclosed coastal body of water, which has a free connection with the open sea, and within which sea water is measurably diluted with fresh water derived from land drainage (Pritchard, 1967). In addition, it is highlighted as a dynamic ecosystem affected by twice-daily rhythm tides. The characteristics above form the unique water environments in the estuary. According to the mixing pattern of sea water and fresh water, estuaries can be recognized into three types, namely ①negligible, ②moderate and ③intense estuaries (Figure 1.1). For type ①, River flow dominates in this system, the outgoing freshwater floats on top of the saline water, a sharp density interface of sea water and fresh water is relatively clearly. Sea water gradually mixes vertically from the bottom to the top of freshwater. This mixing pattern occurs in the estuary with large discharge or neap tide periods. The type ② is a kind of status in between ① and ③, salinity gradient exists along both vertical and horizontal directions. For type ③, tidal flow is greater than the river discharge, which results in strongly mixing along the vertical direction. Salinity gradient exists only along horizontal directions. This kind of mixing pattern occurred in estuary with fierce changes of tidal amplitude or spring tide periods. Different mixing patterns of fresh and sea water result in diverse distribution of salinity in temporally and spatially, and impact the material cycling.

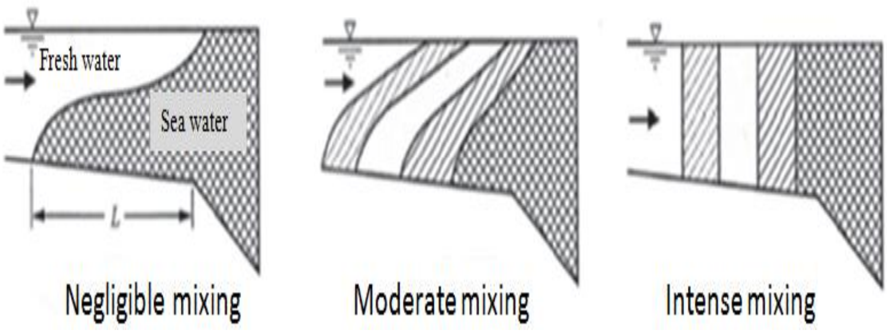


Figure 1.1 Schematic images of the mixing pattern of seawater and freshwater

(Source: Ministry of Land, Infrastructure, Transport and Tourism,
http://www.mlit.go.jp/river/shishin_guideline/gijutsu/gijutsukijunn/chousa/pdf/14.pdf)

The water of estuaries tends to be very turbid as a great amount of silt and clay particles in suspension are carried from the estuary and upstream. The rate of sediment deposition can be faster due to physical procedure, salt flocculation. Additionally, fiercely changed temperature, water level as well as the diverse topography are influenced by tidal motion and wave erosion. These complex environmental variations result in peculiar habitat for livings. Therefore, the number of species is limited compared than adjacent aquatic ecosystems (freshwater ecosystem and marine ecosystem) due to unpredictable variations in salinity (physiological stress), water movement and turbidity (physical stress) (Figure 1.2).

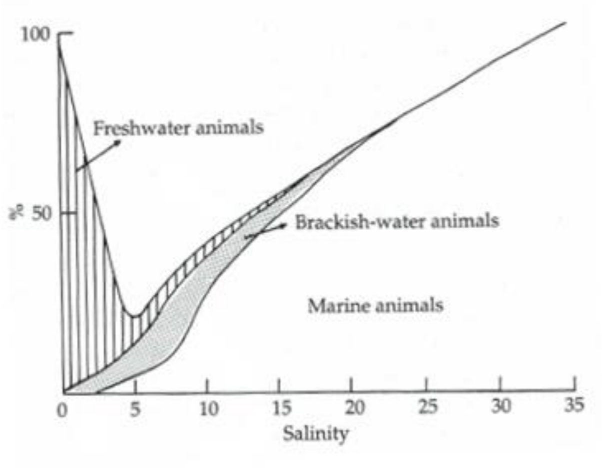


Figure 1.2 Generalized penetration of marine, freshwater, and brackish water animals into an estuary in relation to salinity (McLusky and Elliott, 2004)

By contrast to the decline in the diversity of species, it must be emphasized a abundance of individual species in estuarine ecosystem (McLusky and Elliott, 2004). Slow water flow and salinity intrusion bring a large amount of nutrient and suspended organic matter to estuary from river and sea respectively. Therefore, estuarine ecosystem shows high productivity characteristics (Koichi et al. 2010).

Estuaries support many important ecosystem functions including maintaining habitat, conveyor belts, filter strips, buffer zone, and transporting materials (Duan, 2010). Estuarine ecosystem is considered as one of the highest economic ecosystems (Costanza et al. 2000). Especially, estuaries provide nursery habitat for young migratory fish and estuarine fish. Wetlands in estuaries take roles of water purification by absorbing nitrogen and phosphorus deriving from several sources including animal waste, fertilizer; provide food source for juvenile fish and benthos.

1.1.2 Corbicula bivalves in Japan

Corbicula japonica, *leana* and *Sandai* area three native *Corbicula* species have been widely recognized in Japan (Nanbu et al., 2004), and obtain particles through filtration by holding their inhabit siphon above the sediment surface. It took 43% of the total inland fisheries (in 2008), so that it is one of the most important fishery resources in Japan (Figure 1.3). Among these three species, the catch of *Corbicula japonica* accounted for 99% of *Corbicula* fishery.

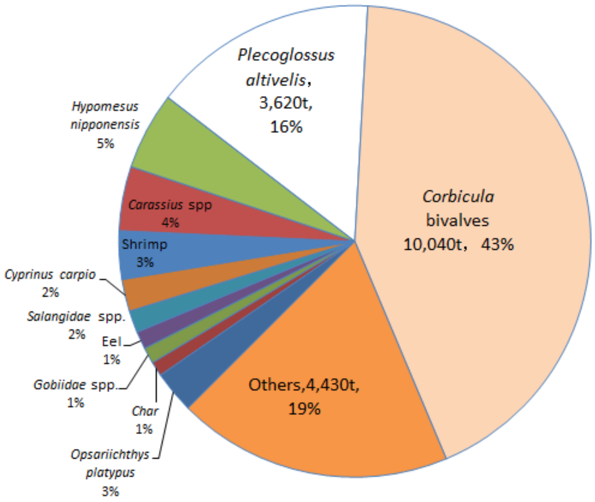


Figure 1.3 The catches for inland fisheries in Japan (production statistics of fishery and aquaculture industry of 2008 from the Ministry of Agriculture, Forestry and Fisheries of Japan)

Corbicula japonica is considered as dioecism organism, commonly found in brackish rivers or lakes (Figure 1.4 (a)). The planktonic larvae undergo 3~10 days suspended life, settle and bury in the sediment or mud substrate. Since *Corbicula japonica* has been expected for having high capacity of water purification, it was proved that nitrogen load from upstream emissions and leaching could be reduced by around 10.7 % by filter feeding from the water column. (Furuhata et al., 2008).

Corbicula leana is considered as hermaphrodite organism and a freshwater bivalve (Figure 1.4 (a)). For the inner surface of shell, it showed white color in the center, and dark purple in the edge. It has a large geographic distribution, extending throughout most of Japan. *Corbicula leana* has a certain level of tolerance to pollution, and unlikely to be caused a significant decline in the population and pesticide. Thus, it can have dramatic effects both on the qualitative and quantitative characteristics of phytoplankton communities, principally due to a very high filtering rate (Hwang et al., 2004).

Corbicula sandai (Figure 1.4 (a)), a dioecism freshwater bivalve, is endemic species of in Lake Biwa. The planktonic larvae undergo several hours of suspended life, then settle and bury in the sediment substrate. The inner surface of shell is lilac color. The catch of *Corbicula sandai* accounted for more than 50% of the total fishery in Lake Biwa. However, the catch of *Corbicula sandai* has significantly decreased from 6,072 tons (1957) to52 tons (2007) (Annual report on agriculture, forestry and Fisheries of Shiga Prefecture).

Corbicula fluminea is exotic species (Figure 1.4 (b)). Normally, it is dioecism, but some hermaphrodites (Yan et al., 2008). For the inner surface of shell, it showed purple color in the center, and brown in the edge. It is a native freshwater bivalve in Taiwan, extending in Asia and throughout most of Japan. Since *Corbicula fluminea* is basically same to *Corbicula leana* in morphology, it is difficult to distinguish them by naked eyes.

(a) (b)

Figure 1.4 The native *Corbicula species Corbicula leana*, *Corbicula japonica* and *Corbicula sandai* (a), exotic bivalve *Corbicula fluminea* (b)

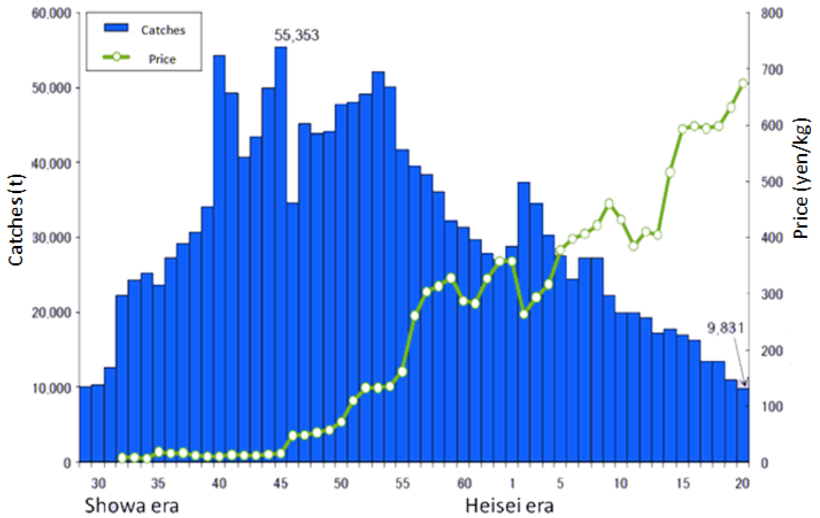


Figure 1.5 The secular change of the yield catches and unit price for *Corbicula* bivalves (Japan Fisheries Resources Conservation Assoc. http://www.fish-jfrca.jp/02/pdf/pamphlet/094)

The catches of *Corbicula* bivalves have reached 50,000t during the periods of Showa 40 ~ 50 years, which declined to 10,000t recent years. The continuous descent of catches was attributed to environmental changes caused by the engineering construction in river estuaries. It was reported that in Tone River, Nagara River and Chikugo River, due to reduction of brackish water area desalination of saline water caused by construction of barriers, the spawning and reproduction were prevented (Japan Fisheries Resources Conservation Assoc.).

1.1.3 Human impacts on estuarine rivers in Japan

In Japan, about three-fourths of the national land is mountain. Due to the rapid flow related to the steepness of slopes and shortness, the low land estuaries are liable to flooding. Since alluvial plains are always suffering from flood, a lot of engineering constructions such as levees, bank protections, channel dredging and guides have been built on the river channel which disturbed the natural river ecosystem, tended to decrease spatial and temporal heterogeneity of habitats for *Corbicula* bivalves.

The concrete reinforced banks accelerate the water flow and promoted river channel homogenization, which cause a large area of the riparian vegetation and dune disappeared in the river, the area of aquatic habitat decreased. A larger number of permanent barrage and temporary barriers (weirs) have been installed in estuaries-to protect low lying area from the flood due to high tide and storm surges. The interference of hydraulic patterns within the estuary by the presence of such structures changed the physical environment as well as biological communities. The tidal amplitude reduction (flood tide is not so high, ebb tide is not so low) result in reduction of intertidal area and diminishing of wading bird. The increasing residence time promote primary production, affected the water quality involving the benthic filter feeder and the whole food chain (Nienhuis et al., 1994). Furtherly, these barriers inferred the distribution of *Corbicula* bivalves by preventing the salinity intrusion or changing the distribution of salinity.

Human recognized that the estuarine ecosystem has been suffering from much of artificial engineering and which probably resulted in decreasing of *Corbicula* bivalves. The methods of improvement and conservation for *Corbicula* bivalves' fishery have been exploring.

1.1.4 Functions and effects of groin

Groin originally has been developed in the field of channel regulation engineering. It was described as a structure extending outward from banks with purpose of deflecting current or wave away from the bank in seashore (Kuhnle et.al 2002), and was also used in rivers to protect banks from erosion caused by flow attacking. In the main channel area, the flow velocity accelerated, while in the return flow zone (in front and behind of groin), the flow velocity decreased and formed stagnant zones (Figure 1.6) (Yang and Cheng, 2014); the reduced flow velocity promoted sediment deposition and resulted in vegetation invasion between adjacent two of the groins; as the result of flow separation, a horse-shoe vortex and a wake vortex developed in front and behind of the groin, and caused the local scour holes (Figure 1.7) (Zhang et al., 2008; Alauddin et al., 2010). Many previous studies have concentrated on the topics of the changes of physical properties caused by the groin installation, such as the flow velocity, sediment deposition and distribution, bed deformation and local increased water depth. These changes of the physical environment are bound to ecological function changing. The functions of groins on river ecosystem were determined by the changes of physical environmental factors in groin area mentioned above.

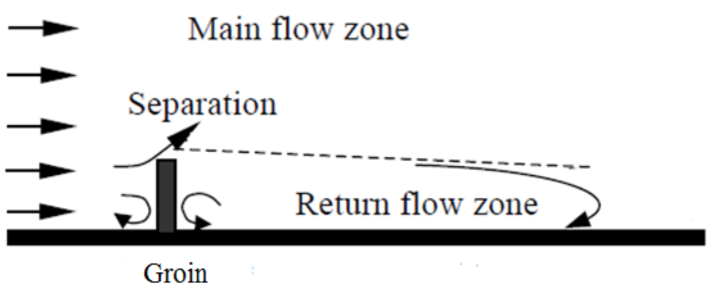


Figure 1.6 Schematic image of flow field with the groins (Zhang, 2008)

After groin completion, flow regimes changes. In the main channel area, the flow velocity was considerably enhanced, while flow velocity decreased around the head and behind of the groin area due to backwater phenomenon (Figure 1.6). The diverse flow velocities might provide appropriate or adverse environmental conditions for benthic organisms or fish (Yang and Cheng, 2014). Wang (2011) showed that the biomass and densities of benthic animals in the front and the head of groin were significantly higher than those behind the groin in related to the differences in flow velocity conditions, by investigating in the Xi River, China. Since sedimentation and vegetation promoted between two of adjacent groins, the river corridor was extended which might provide wider and more diverse habitat for benthic organisms and fish. The local scour holes and hydrostatic area provide habitats and havens for various aquatic organisms during floods and storms. Shields et al. (1995) documented numbers and sizes of fish individuals were significantly larger in such scour holes.

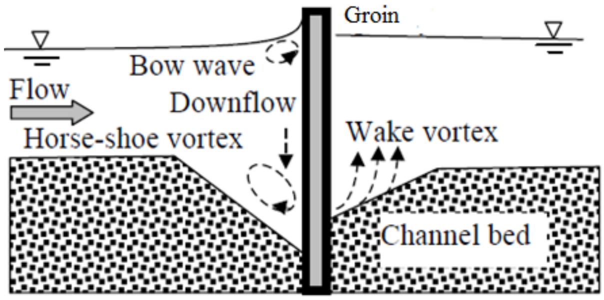


Figure 1.7 Local scour holes around groins (Zhang, 2008)

These studies mentioned that groins took positive effects on river ecosystem. The installing of groins in river channels could increase biodiversity and bio-richness by created habitats with diverse flow structures and substrate patterns, such as deep pool, shallow riffle, stony cascade and muddy stagnant water. It is expected that groins play a role in improving habitat conditions for *Corbicula* bivalves by restoring natural river ecosystem.

1.2 Previous studies

1.2.1 The effects of groin on biological organisms

In the previous works, effect of groins on the upper stream of mountain area (e.g. Wu and Cheng, 2012), lake (e.g. Wang et al., 2007) and sea beach (e.g. Walker et al., 2008) have been mainly investigated. Fish and benthic invertebrates have been mostly selected as objectives to clarify the relations between environmental factors and organisms. Fish may be at the top of the food chain of the aquatic ecosystem, can quickly respond to environmental changes and reflect the ecological conditions, comprehensively. Benthic invertebrates constitute food chain in the second trophic level connecting primary production and fish have characteristics of longer life cycles and limited migration. Hence, they have been often used as indicators for long-term environmental changes.

McCabe et al. (1990) compared benthos, fish and sediment characteristics between pre-and post-groin construction in Columbia River. The density of benthic invertebrates, diversity (H’) and the dominant species (*C. salmonis*) were higher in post-groin construction. The proportions of sediment generally did not dramatically change. The authors suggested that groins installation did not appear to adversely affect the benthic invertebrate short-term.

Agnieszka et al. (2015) detected the effect of river bed regulation resulted from the groins and channelizing on attributes of habitats and ostracod communities. It was clarified the conductivity, total dissolved solids, salinity and vegetation (*Phalaris arundinacea L.*) were the highest in the groin area. The ostracod community was strongly affected by vegetation coverage and detritus content in the sediments. This study confirmed the occurrence of diversified habitats in groin field related to deposited sediments, degrees and types of vegetation.

Walker et al. (2008) investigated the effects of a small groin (perpendicularly built to the shoreline) on beach properties and macro benthic assemblages in southern Queensland, Australia. The installation of groin resulted in deposition in the one side and erosion in the other side. Finer grain size, higher sediment moisture content sediment properties occurred in deposition side. Macro faunal abundance and diversity were significantly greater in the deposition side than in the erosion side. Using the BIO-ENV routine method, it mentioned that distance from groin, height of spring tide and sediment moisture content were primary environmental variables in affecting the macro faunal assemblages.

Fladung et al. (2003) detected abiotic environmental key variables which determined fish assemblages in 15 groin fields (defective groin, repaired groin, intact groin) and training walls in Elbe River. The low fish diversity was found in poorly structured, strongly silted groin fields. This article suggested that the patterns of groin determined the hydro-geomorphological variables and fish assemblages.

Based on the previous studies, there are three points should be emphasized. Firstly, there are few findings about how the groins affect the ecosystem in tidal brackish rivers (river estuary). In Japan, series of groins have been installed to deflect the flood or tidal current in many of low land river estuaries such as, the Kiso and Ibi-Nagara Rivers, the Yodo River, the Ishikari River, etc. Groins coupled with the dramatic changes of tidal motion might have caused more complex effects on estuarine ecosystem. Therefore, in low land estuaries, we should clarify the effect of environmental variations caused by groin installation on the organisms which might provide scientific information and method for estuarine ecosystem management, estuarine ecosystem rehabilitation and conservation.

Secondly, previous studies mainly discussed the relationships between environmental factors and the biological communities caused by groin installation. It illustrated that the existence of groin created diverse habitat by changing hydraulic process and sediment deposition, improved the biodiversity. However, it is rarely investigated the effects of environmental changes caused by groin installation on *Corbicula* bivalves although it is considered as the important fishery in river estuarine ecosystem in Japan.

Lastly, the relative position from groin affected distribution of benthic community. Thus, it is necessary to discuss the effect of groin on distribution of *Corbicula bivalves* by comparing different relative positions to the groin.

1.2.2 Habitat environment and food sources for Corbicula bivalves

Furuhata et al. (2007) discussed the effects of surface environment of sand bar in tidal estuary on distribution of *Corbicula* bivalves. It was found that fine-grain fraction rate (less than 10%), low organic matter(less than 3%) and higher periodical inundation (more than 0.8) are the critical and suitable environment conditions for the *Corbicula* bivalves. Nakamura et al. (1998) investigated habitat environment for *Corbicula japonica,* water depth (< 4m), organic matters in sediment (measured by ash free dry weight (AFDW) <14%) and silt rate (<50%) were the important conditions for the *Corbicula japonica*.

Maru et al. (1999) tested the behavioral responses of *Corbicula japonica* to different bottom sediment sizes. It was found that in medium sand (diameter: 250~500μm) and fine to very fine sand tanks (diameter: 63~250μm), vertical movement of *Corbicula japonica* was rapidly. In very coarse to coarse sand and silt-clay sediment tank, the burying and upward movements were hindered.

Kasai et al. (2005) mentioned that the terrestrial organic matter (TPOM) brought by river flow and utilized as the primary food source for *Corbicula japonica* based on C and N isotopic signatures and concentrations weighted mixing model. In the lake investigation, carbon and nitrogen stable isotope ratios between bivalves and particulate organic matters (POMs) indicated that the bivalves in Lake Ogawara and Lake Shinji assimilated autochthonous phytoplankton owing to the longer residence time for river water (Kasai et al., 2006).

The effect of habitat environment（hydrological and substrate conditions） on distribution of

Corbicula japonica and food sources have already been discussed respectively in lakes or river estuaries. However, few of findings concentrated both of two aspects in the same lakes or rivers simultaneously. On one hand, hydrological and substrate conditions impacted on distribution of *Corbicula japonica*; on the other hand, hydrological conditions and topography also influenced transport of material, which affected the species and the amount of food sources. Thus, water environment factors and substrate conditions followed by food conditions should be emphasized in discussing the influence of the environmental factors variations caused by installation of groins on *Corbicula* bivalves.

1.3 Study objectives and contents

In this study, we target on the effects of environmental variations caused by installation of groins on distribution of *Corbicula* bivalves and their food sources.

We selected Kiso estuary as the investigation field due to where it is characteristic of a series of groins along the right bank from 12 river kilometers (R km) to 25 (R km) and famous fishery for *Corbicula* bivalves. They were completed in the Meiji era leaded by engineers from the Netherlands in order to resist the flood caused by confluence of three major rivers. After 120 years since then, the geomorphology of Kiso estuary has been remarkably changed. In consequence of installation of groin, rapid flow and low river bed formed in mainstream area; stagnant zone, however, in the area with groin, the sour holes and sediment deposition occurred. It means that the discrepancy of hydrological and substrate conditions exist in cross-section, which create diverse habitats for organisms and probably bring different impacts on organisms. In present study, we focus on the effects of groins installation on habitat of *Corbicula* bivalves in marginal areas (the area with groins and the area without groin along the left bank). The obvious topographies changed not only exist in cross-section (with groin and without groin), but also along the longitudinal gradient of estuary. Therefore, we examine the influence of spatial shift of environmental variables on *Corbicula* bivalves along two directions.

In current field, the suspension-feeding bivalves, *Corbicula bivalves* (*Corbicula japonica and Corbicula leana*) dominated benthic community (Mizuno et al., 2006) in Kiso estuary, it was reported that *Corbicula bivalves* in sub tidal zone were more productive than those in inter tidal zone (Tashiro et al., 2010; Furuhata et al., 2008). The relative position from groin affected distribution of benthic community, in this study I targeted on compare the differences of inhabitation of bivalves in scour hole in the area with groins and without groin in subtidal zone.

With this aim, I will ① discuss spatial discrepancy of environment variables, biomass and density of *Corbicula* bivalves in different landscapes; ②find the critical environmental factors controlling the *Corbicula* bivalves habitat which might assist in protecting the *Corbicula* bivalves fishery in estuary with series of groin; also, we would try to evaluate their biomass and density quantitatively with the critical environmental factors.

In estuary, the suspended particulate organic matters (SPOMs) derived from terrestrial organic matter (TPOM), marine organic matter (MPOM), and autochthonous organic matter-estuary organic matter (EPOM). As mentioned above, primary production and SPOMs distribution are often disturbed by barrier-like constructions (McLusky and Elliott, 2004). Thus, it is necessary to estimate food sources for *Corbicula* bivalves in different landscapes in order to understand the effect of food condition variations caused by groins installation on *Corbicula* bivalves' habitat. With this aim, I will discuss the characteristics of distribution of SPOMs, food sources and compositions for *Corbicula bivalves*, and also I will examine whether food sources change or not depending on different growth stages for these two *Corbicula* bivalves.

Chapter 1 introduces the characteristics of estuary ecosystem with emphasizing their important ecological functions. The status of *Corbicula* bivalves in inland fishery and the descent of the catches are also introduced. The functions of groin are described from the viewpoint of expectations to create natural estuarine ecosystem for improve the habitat environment conditions for *Corbicula* bivalves. By reviewing the previous study, the objectives for this study are described.

Chapter 2 introduces the trophic condition in the river estuary, the discriminations in stable isotope signatures and the analytical method to estimate food sources using stable isotopic signatures.

Chapter 3 explains the relevant information about the field. Firstly, pervious researches are reviewed in Kiso estuary encompassed geomorphologic formation procedure, hydraulic feature, salinity intrusion, sediment characteristics influenced by construction of a series groin. Secondly, the influences of environmental variables on *Corbicula japonica* in other lakes or estuaries are illustrated. Based on the integration of reviewing of previous studies, it is recognized that the effects of environmental factors on *Corbicula bivalves* distribution are need to be quantitatively described since the environmental variables combined together to influence their inhabitation.

Chapter 4 discusses the effect of spatial shift (longitudinal and transverse directions) of environment variables on *Corbicula* bivalves (biomass and density). The sampling locations are designed in the area with, without groins and in thalweg in multiple cross-sections. Water environmental factors, substrate conditions, diet conditions, biomass and density of the two species bivalves were investigated and measured. Two-way ANOVA is utilized to evaluate the main effects of the longitudinal direction and transverse direction in all environmental variables and each of *Corbicula* bivalves. The correlation between each of two environment variables and between environment variables and *Corbicula* bivalves are discussed in order to understand critical environment variables for *Corbicula* bivalves. Multiple regression analysis is performed to estimate the biomass and density by critical environmental variables.

Chapter 5 discusses the effects of different landscapes caused by groin installations on *Corbicula* bivalves' food sources variations with potential food sources (suspend particulate organic matters) in upper and lower estuary. Based on signatures of carbon and nitrogen stable isotope ($\delta^{13}C$ and $\delta^{15}N$), I discuss the origin and distribution of suspend particulate organic matters in the groin segment. Adopting the "Isosource" mixing model with these signatures, I evaluate the food sources in each landscape.

Chapter 6 makes the conclusions and plan for future works.

Reference

Agnieszka, S. (2015) Effects of river bed regulation on habitats and communities: A case study for ostracods in the Oder River, Poland, *International Review of Hydrobiology*,100: 69–78.

Alauddin, M., Tsujimoto, T., (2011) Optimum design of groynes for stabilization of lowland rivers, *Journal of Japan Society of Civil Engineers, Ser.B1 (Hydraulic Engineering)*, 67 (4):145-150.

Costanzo, S. D., Odonohue, M. J., and Dennison, W.C., (2000) Gracilaria edulis (Rhodophyta) as a biological indicator of pulsed nutrients in oligotrophic water. *Journal of Phycology*, 36: 680-685.

Daily, G. C., Alexander, S., Ehrlich, P.R., Goulder, L., Lubcheno, J., Matson, PA., Mooney, HA., Postel, S., Schneider, S.H., (1997) Ecosystem services: benefits supplied to human society by natural ecosystems, *Ecological Society of America*, Issues in Ecology, 2

David Allan, J., Castillo, M.M., (2008) Stream Ecology, Springer

Duan, X.H., Wang, Z.Z, Xu, M.Z.,(2010) Benthic organism and river ecological assessment, *Tsinghua University Press*(In Chinese).

Fladung, B.E., Scholten, M., Thiel, R., (2003) Modelling the habitat preferences of preadult and adult fishes on the shoreline of the large, lowland Elbe River, *Journal of Applied Ichthyology*, 19:303–314

Hwang, S., Kim, H., Shin, J., Oh, J. and Kong, D.,(2004)Grazing effects of a freshwater bivalve (*Corbicula leana* Prime) and large zooplankton on phytoplankton communities in two Korean lakes, *Hydrobiologia*, 515: 161–179.

Koichi, Y., Shimomura, K., Inukai, M. Mizuo, H., (2010) Investigation of water quality and sediment in the tidal river－Katabira river. *Annual Report of Yokohama-shi Environmental Science Research Institute*, 34: 24-27 (in Japanese).

Konsulova, T., Doncheva, V., (2014) Ecological impact assessment of groins in varna bay (black sea, bulgaria)- a prerequisite for application of environmentally friendly shore protection structures, *Acta Zoological Bulgarica*, 66 (1): 73-81.

Kuhnle, R., Alonso, C., and Shields, F., (2002) Local Scour Associated with angled spur dikes. Journal of Hydraulic Engineering, 128: 1087-1093.

Kyuka, T., Fujita, M., Takebayashi, H., (2012) Sediment transport characteristic around spur dike installed in the rigid bed, *Annuals of disaster prevention research institute*,55(B): 427-436 (In Japanese).

Lalli, C.M., Parsons, T.R., (1993) Biological oceanography: An Introduction, *Elsevier*, 261.

Lu, Y.J., and Zhou, Y.T., (1989) Study on velocity field near redeveloping region behind groin-like Structures, *Journal of Hydrodynamics*, 3.

McCabe ,G. T., Hinton,S.A., Emmett, R.L., (1990) Benthic Invertebrates, Sediment Characteristics, and Demersal Fishes Off Cottonwood Island, Columbia River, Before and After Rock Groin Construction, 1987-1988, U.S. Army Corps of Engineers.

McLusky, D.S., Elliott, M., (2004) The estuarine ecosystem- ecology, threats and management, *Oxford University press*.

Ministry of Land, Infrastructure, Transport and Tourism (2014) Environmental Survey in Brackish and Tidal Zones, Technical Criteria of Field Survey for River and Erosion Control

Works, http://www.mlit.go.jp/river/shishin_guideline/gijutsu/gijutsukijunn/chousa/pdf/14.pdf (in Japanese)

Mizuno, T. and Sekiguchi, H., (2006) Catch fluctuation of brackish water clam *Corbicula japonica* in Kiso estuary, Japan, *The Japanese Society Fisheries Science*,72(2):153-159 (Japanese version).

Nienhuis, P. H., Smaal, A. C., (1994) The Oosterschelde estuary, a case-study of a changing ecosystem: an introduction, *Hydrobiologia*, 282 (1): 1-14.

Pritchard, D.W., (1967) What is an estuary: physical viewpoint, *American Association for the Advancement of Science*, 83: 3-5.

Shields, F. D., Jr., Cooper, C. M., and Knight, S. S., (1995) Experiment in stream restoration, *Journal of Hydraulic Engineering*, 121: 494-502.

Van Riel, M. C., Van Der Velde, G., Rajagopal, S., Marguillier, S., Dehairs, F., Bij De Vaate,A. (2006) Trophic relationships in the Rhine food web during invasion and after establishment of the Ponto-Caspian invader *Dikerogammarus villosus*, *Developments in Hydrobiology*,187: 39-58.

Walker, S. J., Schlacher, T. A., Thompson, M.C., (2008) Habitat modification in a dynamic environment: The influence of a small artificial groyne on macrofaunal assemblages of a sandy beach, Estuarine, *Coastal and Shelf Science*, 79: 24-34.

Wang, W. D.,Yin, C. Q., Lu, J. W.,(2007) Application of submerged groin systems in the ecological restoration of littoral zones. *Chinese Journal of Environmental Engineering*, 1 (2):135-138 (In Chinese).

Wang, Z.Y., (2011) Report on the effect of river channel improvement on ecological ecosystem, *Nanjing Hydraulic Research Institute* (In Chinese).

Wu, R.X., Chen, Y.R., (2012) Estimation of spur dike-affected fish habitat area. *Chinese Journal of Applied Ecology*, 23 (4):923-930 (In Chinese).

Yan, H., Lee,X.Q., Zhou, H., Cheng, H. G., Peng, Y., Zhou, Z.H., (2009) Stable isotope composition of the modern freshwater bivalve *Corbicula fluminea, Genchemical Journal*,43: 379-387.

Yang, M.M., Chen,Y.M., (2014) Research on influences and countermeasures of spur dike on ecology of regulation river reach, *Journal of Waterway and Harbor*,35: 544-549(In Chinese).

Zhang, H., Zhang, X., Nakagawa, H., Xu, W., Lin, P., Mizutani, H. (2011) Characteristic of grain size distribution in groin field and their environment implications, *Annuals of Disaster Prevention Research Institute Kyoto University*,54B: 511-523.

Chapter 2

AQUATIC ENVIRONMENT AND STABLE ISOTOPE ANALYSIS

2.1 General

Tidal estuaries, connecting with river and sea, promoted various materials (particulate organic matters) produced in situ or imported into the estuary (Middelburg et al., 1998), where allochthonous particles include marine, terrestrial inputs, while autochthonous particles derive from primary production such as phytoplankton, microphytobenthos and plants. Estuaries are more active for the material cycle than other aquatic ecosystems such as fresh water ecosystem and marine ecosystem. Due to full tidal cycle (from spring to neap tides 28 days), the sea water is dominant in spring tide and outgoing fresh water is dominant in neap tide. In river estuary the material flow is in unsteady state, and materials distributions are uneven in temporally.

Particulate organic matter (POM) is considered as the most important food source to primary consumer (benthos). The origin, migration and transformation of POM are critical issues related to material cycling and energy flow in estuarine ecosystem. In this chapter, we would illustrate the characteristics of POM in river estuaries and their transformation in food web.

Stable isotope ratios are the most available indicator for tracing sources of POM. Isotopes are atoms of elements with different numbers of neutrons. Most elements exist in two or more forms, known as isotopes. Isotopes have the same number of protons but differ in their number of neutrons, resulting in different masses. This variation in the relative abundance of stable isotopes results from tiny mass differences that cause the isotopes to act differently in chemical reactions and physical processes. The lighter isotope is generally the more common one (Hobson et al., 2008) forms weaker bonds than the heavier one and tends to react faster. The change in isotopic abundance is called fractionation. It indicated that isotope fractionation occurred when the nutrient delivered to next trophic level.

Different organisms showed different stable isotope ratios. Generally, the relative amounts were utilized to reflect stable isotope ratios, expressed by the standard δ as parts per thousand (Werner et al., 2001) as follows:

These values are calculated as follows

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

where X is the element such as ^{13}C or ^{15}N, R sample is ratio of heavy and light isotope (e.g.$^{13}C/^{12}C$ for carbon,$^{15}N/^{14}N$ for nitrogen). The quotient of the ratios in the sample relative to the standard is the δ value. The numerical values associated with the isotope ratio (such as $\delta^{12}C$) are the atomic masses of the isotopes and are accounted for by differences in the number of neutrons contained in the atom's nuclei. Therefore, an increase in the δ values denotes an increase in the amount of the heavier isotope component; while a decrease in the values denotes a decrease in the heavy isotope content (Peterson et al., 1987). $R_{standard}$ is ratio of heavy and light isotope general international standard. Pee Dee Belemnite (PDB) (Craig, 1957) and atmospheric nitrogen Mariotti (1983) were used as the isotope standards for carbon and nitrogen, respectively.

2.2 Food sources in river estuary

Terrestrial organic matters are composed by detritus of 'C_3'- plant and 'C_4'- plant carried by surface runoff to the estuary. The significant differences between 'C_3'- plant and 'C_4'- plant in carbon isotope ratios mainly result from different photosynthetic pathways. $\delta^{13}C$ in C3 plants ranged from -34‰ ~ -23‰, however, $\delta^{13}C$ in C_4 plants exhibited relatively heavier values, ranging from -16% ~ -9‰ (Creach et al.1997). $\delta^{15}N$ values of terrestrial plants are influenced by multiple nitrogen resources and plant requirement with no obviously differences between C_3 and C_4 mechanism, ranged between 0 and 4‰.

Compared with terrestrial ecosystem, $\delta^{13}C$ of the plants in freshwater ecosystem show relatively higher values of about -24‰ ~ -19‰ (average of -21‰) (Kendall et al., 2001) due to restriction of CO_2 diffusion (Sweeney et al., 1978). δ^{15} N also show significantly higher values than terrestrial plants. In marine ecosystem, seagrass shows relatively heavier $\delta^{13}C$ values, from -13 ‰ to -7 ‰. The higher $\delta^{13}C$ of in seagrass result from the heavier $\delta^{13}C$ values of carbonate ions in sea water.

Since diverse POMs assemble in estuary, Middelburg et al. (1998) distinguished POM in Schelde estuary by carbon and nitrogen stable isotope ratios and C/N value. It found that terrestrial organic matter ($\delta^{13}C$≈-26‰, δ^{15} N≈3.5‰ and C/N ≈21‰) mainly composed the sediment organic matters, marine organic matter($\delta^{13}C$≈-18‰, δ^{15} N≈9‰ and C/N ≈8‰), riverine ($\delta^{13}C$≈-30‰, δ^{15} N≈9‰ and C/N ≈7.5‰) and estuarine organic matter ($\delta^{13}C$≈-29‰, δ^{15} N≈15‰ and C/N ≈8‰) composed the suspended organic matters in estuary.

Ogawa et al. (1994) assumed the POM in Tokyo Bay originated only from two end-members (terrestrial and marine) considering significant differences in stable isotope ratios between organic matters originated from riverine and marine. The carbon stable isotope of sampling can be expressed by the two end-members model as followed

$\delta^{13}C_{sample} = f\ \delta^{13}C_t + (1-f)\ \delta^{13}C_m$

where $\delta^{13}Ct$ originated from terrestrial plant('C3'- plant), $\delta^{13}Cm$ originated from marine organic matter.

2.3 Estimation procedure of the food source analysis

The stable isotope ratios of animal tissues reflect their diets. Different food sources showed different stable isotope ratios. Fyr et al. (1978) found that $\delta^{13}C$ of grasshopper were significantly correlated with $\delta^{13}C$ their food source ($R^2 = 0.97$). As I mentioned above, isotope fractionations occur as the nutrient transformation from food to organisms. These increased values derived from isotope fractionation are called as trophic enrichment factor (TEF). Generally enrichment of ^{13}C through the trophic network was widely recognized among most animals, leading to a low value of 0 ~ 1‰ (Deniro et al., 1981). In different aquatic ecosystems, the enrichment of ^{13}C shows slight differences, with 0.8‰, 0.5‰, and 0.2‰ in marine ecosystem, estuary ecosystem and fresh water ecosystem respectively. Due to a small difference in $\delta^{13}C$ values between two adjacent trophic levels, the values are always used as food tracers.

The $\delta^{15}N$ of animal tissue were significantly different from their food sources, with higher values of 2 ~ 5 ‰ than their food sources. Therefore, nitrogen stable isotope values are commonly used to trace trophic level. According to these relations, we can understand the relationships between producers and consumers in different trophic levels by stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) plot (Figure 2.1). Also, we can determine the main food sources if the stable isotope ratios of animal understand.

Based on stable isotope ratios and relations, we can not only determine the main food sources in the animal diet, but also estimate the relative proportions of each food sources (Hobson et al., 1999). Standard linear mixing models can be used to solve for the unique combination of food source proportions (n+1), by using n kind of isotopes (Phillips et al., 2001). For example, with two isotope tracers (^{13}C and ^{15}N) and three sources, the mass balance equations can be solved to the proportions (f_A, f_B, f_C) of food sources by isotopic signatures ($\delta^{13}C_A$, $\delta^{13}C_B$, $\delta^{13}C_C$) and ($\delta^{15}N_A$, $\delta^{15}N_B$, $\delta^{15}N_C$) which coincide with stable isotope ratios for tissue of animals ($\delta^{13}C_{consumer\ and}$ $\delta^{15}N_{consumer}$). Here, the $\delta^{13}C$ and $\delta^{15}N$ of the food sources in the equation are the values after isotope fractionation. The mass balance equations show below:

$$\delta^{13}C_{consummer} = f_A\delta^{13}C_A + f_B\delta^{13}C_B + f_C\delta^{13}C_C$$

$$\delta^{15}N_{consummer} = f_A\delta^{15}N_A + f_B\delta^{15}N_B + f_C\delta^{15}N_C \qquad (2)$$

$$1 = f_A + f_B + f_C$$

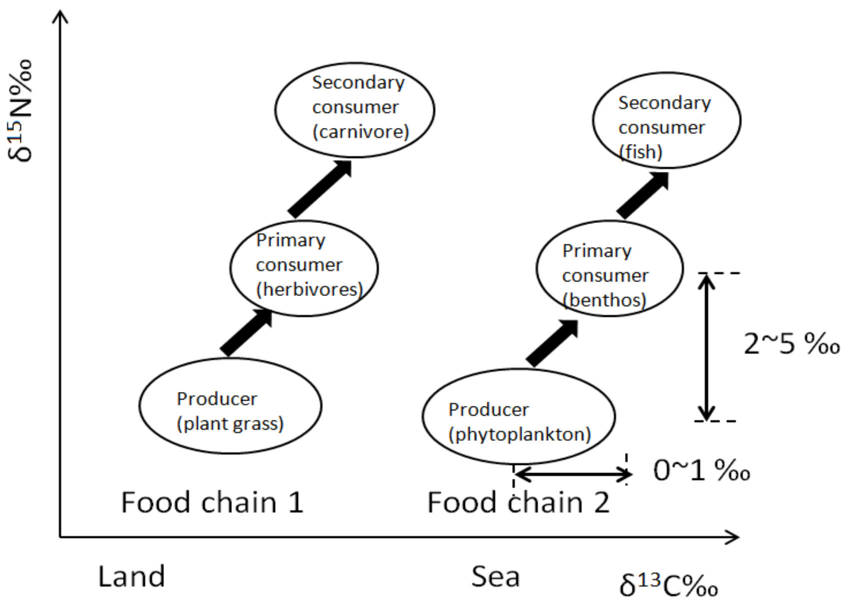


Figure 2.1 The relationships between food and animals described by $\delta^{13}C$ and $\delta^{15}N$

The equations can be extended to include more than three sources. For example, with two isotope systems and four sources, the following equations as:

$$\delta^{13}C_{consummer} = f_A\delta^{13}C_A + f_B\delta^{13}C_B + f_C\delta^{13}C_C + f_D\delta^{13}C_D$$

$$\delta^{15}N_{consummer} = f_A\delta^{15}N_A + f_B\delta^{15}N_B + f_C\delta^{15}N_C + f_D\delta^{15}N_D \quad (3)$$

$$1 = f_A + f_B + f_C + f_D$$

In this situation, no unique solution can be given. However, we can still use the mass balance conservation to find multiple combinations of source proportions which are feasible solutions. Phillips et al. (2003) predicted isotopic signatures of the animals by each possible combination of food sources, then the predicted isotopic signatures of the animals were utilized to compare with the observed values (true values). If there is some small tolerance such as 0.1‰, this combination of source proportions represents a kind of feasible solution. Lastly, we can estimate the frequency of relative contribution for each food source. Phillips et al., (2003) designed the software (IsoSource) to realize this procedure. Figure 2.2 shows an application of this model. The mixing polygon is connected by $\delta^{13}C$ and $\delta^{15}N$ signatures of seven food sources for spring coastal mink in SE Alaska (after correcting for trophic fractionation). Histograms show the distribution of feasible contributions of each source to the mink diet (M). Values shown in the boxes are 1-99% ranges for these distributions, for examples, fish appeared to constitute the majority of the diet (49-63%), crab was considered as an important secondary food sources (19-42%).

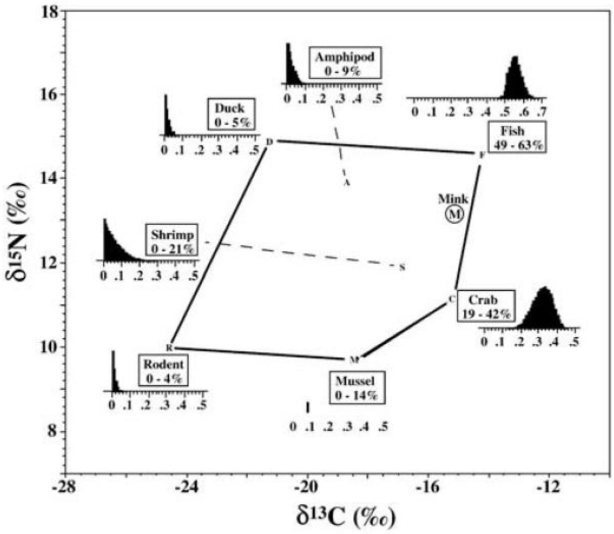


Figure 2.2 Mixing polygon for $\delta^{13}C$ and $\delta^{15}N$ signatures of seven food sources for spring coastal mink in SE Alaska (Phillips 2003)

Reference

Craig, H. (1957) Isotopic standards for carbon and oxygen and correction factors for mass spectrometric analysis of dioxide, *Geochimica et Cosmochimica Acta* 12, 133–149.

Creach,V., Schricke, M.T.， Bertru, G., Mariotti， A. (1997) Stable isotopes and gut analyses to determine feeding relationships in saltmarsh macroconsumers, *Estuarine, Coastal and Shelf Science*,44(5) : 599–611.

Deniro, M.J., Epstein, M. (1981) Influence of diet on the distribution of nitrogen isotopes in animals, *Geochimica et Cosmochimica Acta*, 45:341-351.

Elliott, M., Hemingway, K. (2002) Fishes in Estuaries, *Blackwells*, 52.

Fry, B., Joern, A., and Parker, P. L., (1978) Grasshopper food web analysis: use of carbon isotope ratios to examine feeding relationships among terrestrial herbivores, *Ecological Society* *of America*, 59(3):498-506.

Hobson, K.A., (1999) Tracing origins and migration of wildlife using stables isotopes: a review, *Oecologia*, 120:314–326.

Hobson, K. A., Wassenaar, L. I., (2008) Tracking Animal Migration with Stable Isotopes, *London, UK, Academic Press*.

Kendall, C., Silva, S. R., Kelly, V. J., (2001) Carbon and nitrogen isotopic compositions of particulate organic matter in four large river systems across the United State, *Hydrological Processes*,15:1301-1346.

Mariotti, A. (1983) Atmospheric nitrogen is a reliable standard for natural ^{15}N abundance measurements, *Nature* 303, 685–687.

Middelburg, J. J., Nieuwenhuize, J., (1998) Carbon and nitrogen stable isotopes in suspended matter and sediments from the Schelde Estuary, *Marine Chemistry*, 60: 217-225.

Minagawa, M., Wada, E., (1984) Stepwise enrichment of 15 N along food chains: further evidence and the relation between δ15N and animal age, *Geochim. Cosmochim. Acta*, 48: 1135-1140.

Sweeney, R. E., Liu, K. K., and Kaplan, I. R.,(1978) Oceanic nitrogen isotopes and their use in determining the source of sedimentary nitrogen, *Stable Isotope in the Earth Science*, 20: 9-26.

Peterson, B. J., Fry, B., (1987) Stable isotopes in ecosystem studies. *Ecology, Evolution, and Systematics*, 18, 293-320.

Phillips, D.L., Gregg, J.W., (2001) Uncertainty in source partitioning using stable isotopes, *Oecologia*, 127:171–179.

Phillips, D.L., (2001) Mixing models in analyses of diet using multiple stable isotopes: a critique, *Oecologia*, 127:166–170.

Phillips, D.L., Gregg, J.W., (2003) Source partitioning using stable isotopes: coping with too many sources, *Oecologia1*, 36: 261-269

Werner, R. A., Brand, W. A., (2001) Referencing strategies and techniques in stable isotope ratio analysis. *Rapid Communications in Mass Spectrometry*, 15, 501-519.

Chapter 3

LANDSCAPES AND HABITAT ENVIRONMENTS IN KISO RIVER ESTUARY

3.1 General

Groin construction is considered as one of the most effective methods to create diverse landscapes and restore natural river ecosystem by changing hydrodynamic regimes with geomorphological process. The effects of groin on flow, sediment distribution have been discussed in chapter1.14. The hydrodynamic regimes, sediment deposition and erosion showed different characteristics between mainstream area and marginal area, which caused diverse landscapes. The physical environment conditions in different landscapes are closely relate to the peculiar habitat environment for organisms. Therefore, a part of in this chapter intends to identify the changes of the geomorphologies and the responses of physical environment conditions to installation of a series of groins in the research area of Kiso estuary.

In this field, the suspended feeding bivalves-*Corbicula* bivalves (*Corbicula japonica and Corbicula leana*) dominated the benthic community (Mizuno et al., 2006). Regarding this species, the critical environmental conditions have been clarified in many fisheries such as Shinji Lake, Jiusan Lake. However, few of study concentrated on river estuary with complex artificial constructions. In this chapter, critical environmental factors affecting *Corbicula* bivalves' inhabitation are also intended to be identified by reviewing previous works, and which are utilized to analyze the impacts of their variations in groin segment on distributions of *Corbicula bivalves* in the future work.

3.2 Study location

Kiso River, one of famous rivers in central of Japan, springs from Kiso valley in Nagano prefectural. The length of Kiso River is 229km and the river basin is 5,275 km^2 which supports 1.8 million populations. An abundance of water is utilized for irrigation, hydraulic power generation and industrial water for Nagoya and Ichinomiya City.

Near the river mouth, three major rivers (Kiso, Nagara and Ibi River) confluent together and empty into Ise Bay. Formerly, floods frequently destroyed the houses, facilities, and threatened the livings. On the other hand, they also brought huge area of floodplain and water resource for developing the agriculture. From 1887 to 1912, a project has been launched to separate these three rivers in the low land area by Meiji government with several levees and groins in order to protect the levee from strong flood flow. Totally, 30 groins were constructed along the right bank of the river, from 12 to 25 river kilometers of river mouth (Figure 3.1), with an interval of 100~400 m. The length of groin is about 150~220 m. The groins were divided into two types: one type is permeable groin, made by piles and wood (12-16Rkm); the other is impermeable groin, mainly made by stones and filled by sediment in the cracks (16-25Rkm).

Figure 3.2 shows the monthly average discharge of Kiso river from 2008 to 2012 in Kasamatsu hydrologic station (40.3Rkm). The mean annual discharge is 297.6m^3/s with the maximum discharge and minmun discharge are 93.8 m^3/s in January and 620.6 m^3/s in July respectively. Kiso River is famous for the larger discharge comparing the rivers pouring into

Isebay such as Ibi River (118.7 m^3/s) and Kushida River (33.9 m^3/s).

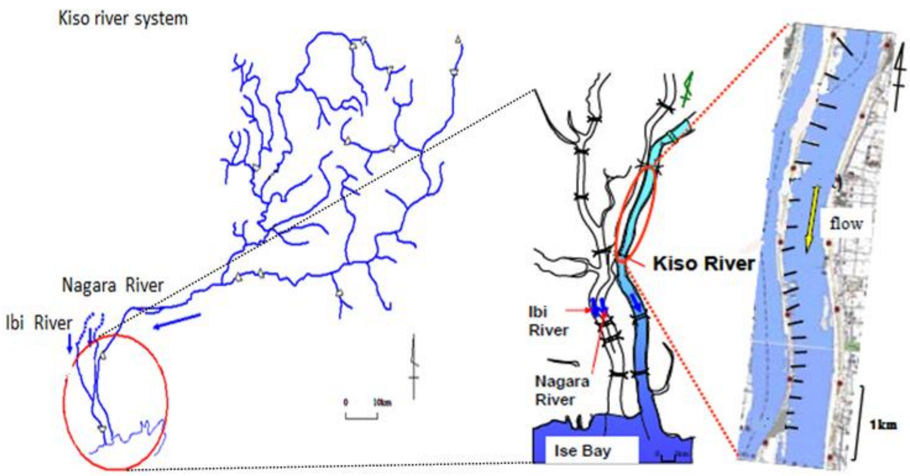


Figure 3.1 Map of Kiso estuary

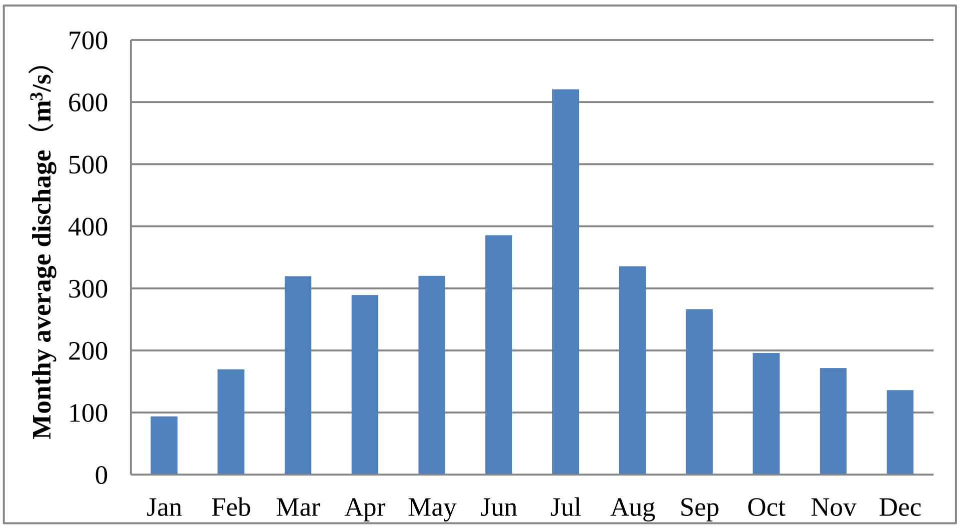


Figure 3.2 Monthly average discharge of Kiso river (Kasamatsu) from 2008 to 2012

3.3 Landscape and Topography

3.3.1 Groins and embayments

Groin is constructed in the form of a barrier, being placed transverse to the primary motion of water, used in seashore to protect the bank from waves and sea erosion, and also used in rivers to protect banks from erosion caused by attack, as well as adopted to divert or guide the flow

(Liu et al., 1989). It is known by several names such as spurs, spur dikes, and transverse dike. Due to controlling sediments function, they are constructed with openings. According to materials of construction, the groin is classified into impermeable and permeable groin. The former one is consist of resistant materials like rock fill or earth core armored with stone grouted, precast plain cement concrete blocks with characteristic of resisting appreciable flow through them taking advantage in deflecting flow away from the bank. Permeable groin is made by wood pile or precast plain concrete pile. It is not strong enough to resist shocks and pressure from flow, but obstructs the flow and slacken it to cause deposition of sediment carried by river streams (Hossain et al., 1981).

Numerous researchers have shown that between two adjacent groins flow was reduced and water exchange was complicated (eg., Liu et al.,1989). Some study suggested that the complex flow condition significantly impacted the bed deformed and morphology changes groin-unit (Zhang et al. 2011). Sediment sorting process was enhanced longitudinally and laterally, which resulted in various substrate environment conditions. The scour holes occurred around groins and form the relative lentic area (Zhang et al. 2008).

Yamashita (2001) mentioned that the amount of sediment deposition in groin-unit was not homogeneous in Kiso estuary, which was a consequence of the shapes of groin (including the angle between groin and flow in mainstream, the distance from groin to mainstream and the positional relation of two adjacent groins and flow in mainstream).The angle between groin and flow was the role parameter for the accumulation of sediment in groin-unit. Larger amount of sediment accumulated in the groin-unit where the groins upward directed against the flow, compared with the right angle pattern groins. It was estimated that the former showed 1.8 times larger sediment accumulation than the latter according to the numerical simulation analysis result (Nezu et al., 2002). These results explained the unequal sediment distributions among each groin-unit in the Kiso estuary. It also can be inferred that the water depth in each of groin-unit might be quite different due to unequal sediment deposition and distribution.

The height of river bed in groin-unit has been elevated due to the sand mining in the main stream 50 years ago. Kitamura et al. (2001) mentioned that relatively higher river bed in groin-unit (compared with thalweg) and the coarseness in upper groin-unit influenced sediment transport and geomorphology of groin segment. The landscapes in the area with groins were divided into 6 patterns (Figure 3.3), referring to differences in amount of sediment and the vegetation and the micro-topography. The micro-topographies presented as ① the local scour holes behind a groin formed by blocking sediment transport and by scouring flow overtopping the groin during flood (Kimura et al. 2001), where water depth is deeper than the area without groins, and water exchanges might be limited. ②The rib-parallel was created by the deposition of fine sand transported by lateral diffusion during flood (Tsubaki et al., 2008).

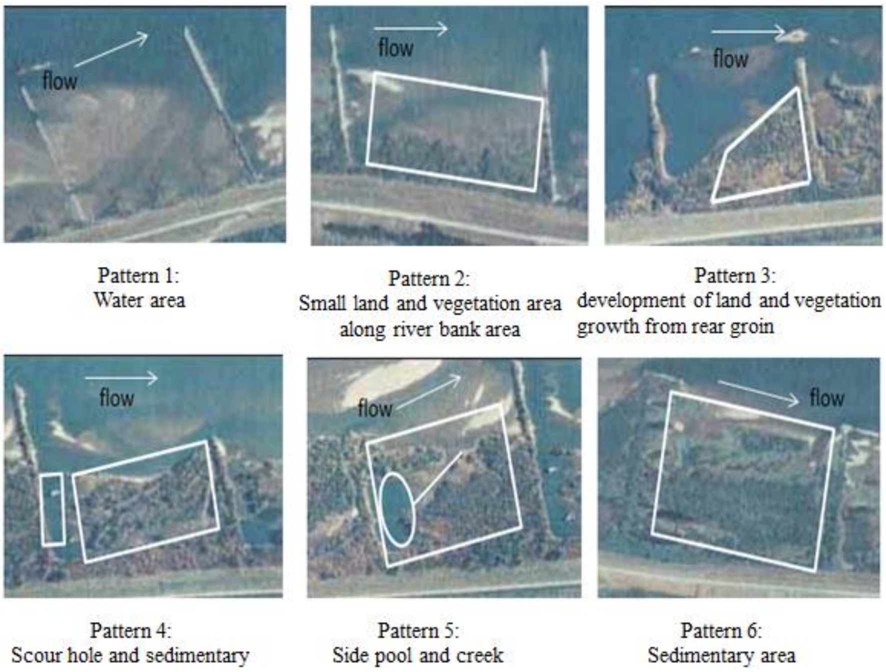


Figure 3.3 Six patterns of the embayment-landscapes in Kiso estuary

3.3.2 Spatial variations of landscapes

3.3.2.1 Riverbed degradation

Figure 3.4 shows the temporal variations of height of river bed along low- water channel of longitudinal gradient from river mouth up to 25R km. The river bed has been declined from 1963 to 2002, since gravel was mined, land subsidence due to excessively pumping of ground water and reduction of sediment transport because of dam construction such as the Kiso weir installed in 26 Rkm in 1970 (River Conversazione in Japan, 2003). Additionally, as we mentioned in chapter 1, groin installation also accelerated flow velocity in mainstream area, which resulted in erosion state of river bed. Especially from 1972 to 1990, river bed degradation in low-water channel has been obviously changed. However, compared with the obvious changed of river bed in low-water channel, there was a little changes rear of the groin-unit. The height discrepancy between these two of landscapes accelerated the terrestrialization and vegetation invasion in area with groins (Tsubaki et al., 2008).

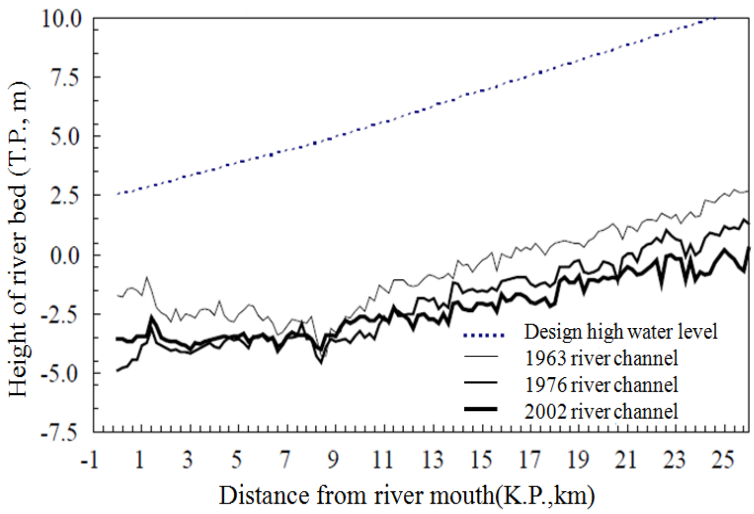


Figure 3.4 Riverbed changes along the longitudinal gradient (Kitamura et.al 2001)

3.3.2.2 Characteristics of embayment with groins

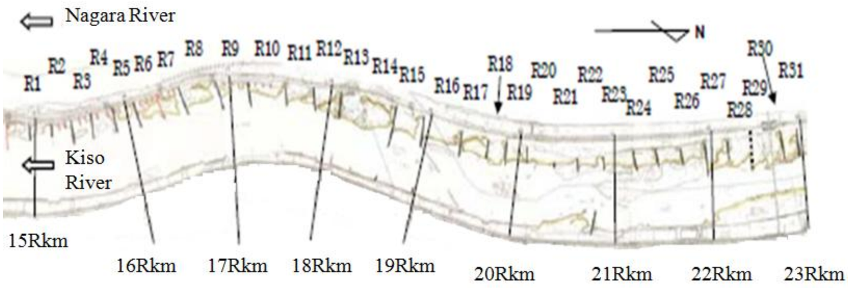


Figure 3.5 Downstream reach of the Kiso River with series of groins (Kitamura et al., 2001)

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20	R21	R22	R23	R24	R25	R26	R27	R28	R29	R30	R31
1963	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1975	1	1	1	1	1	1	1	1	1	1	2	3	5	3	3	2	4	4	4	2	2	2	2	2	2	2	2	4	4	4	3
1982	1	1	1	1	1	1	1	1	1	1	2	5	5	4	3	4	5	4	5	6	3	4	5	5	4	4	5	5	6	4	4
1987	1	1	1	1	1	1	1	1	1	2	2	5	5	4	3	4	5	5	5	6	3	4	5	5	5	4	5	5	6	5	4
1991	1	1	1	1	1	1	1	1	1	1	2	5	6	4	4	4	5	6	6	6	4	4	6	6	6	4	5	5	6	4	4
1995	1	1	1	1	1	1	1	1	1	2	5	6	6	4	4	4	5	6	5	6	4	5	6	6	6	4	5	5	6	4	6

Figure 3.6 The transition and the process we postulated to this segment (Kitamura et al., 2001)

Kitamura (2001) demonstrated that the transition of landscapes along the longitudinal gradient in area with groins. From 17 to 23 Rkm, all of the groin-units transformed into terrestrialization, even though all of them were covered by water in 1963 (Figure 3.3, 3.5 and 3.6). Spatially, the territrialization and vegetation invasion proceeded faster in upper reach than in lower reach. The process of landscape evolution in area with groins indicated that landscapes from 15Rkm to 17Rkm (R1-R9) were characteristic of wide area of water; the sedimentary was developing from 17Rkm to 19Rkm (R9-R16), where it formed a transition zone; the developed terrestrial landscapes were promoted from 19Rkm to 23Rkm (R16-R31). It implied that the landscapes in area with groins are generally divided into three types, created diverse habitat environment conditions for biological communities with obviously different hydraulic conditions, sediment depositions and transportations. Therefore, it is suggested that in the current study the effects of environment variables in these three representative landscapes on organisms should be examined.

3.4 Physic-chemical environments

3.4.1 Salinity distribution **(Shionoya** (2006))

Kiso estuary is exposed to tidal motion with a range of around 2 m. Shionoya (2006) suggested that the groin segment area was characteristic of intense and moderate salinity mixing pattern (Figure 3.7). It indicated that Kiso estuary is characteristic of less salinity gradient in vertical direction and strong material cycling. The numerical analysis showed that brackish zone (low limitation: 0.2～0.5psu， high limitation: 16.5～20psu) extends close to 25Rkm in the area with groin, basing on, which was more extensive than that in area without groins (Figure 3.8). It suggested that a series of groins probably supported more extensive habitats for the brackish communities. Shionoya (2006) also documented that the relative saline water appeared in the area with groins compared with that in the area without groins, indicating a series of groins probably provided relative saline conditions the for brackish communities (Figure 3.9).

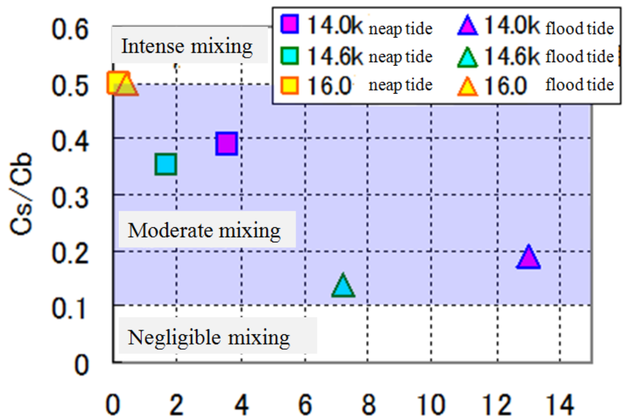


Figure 3.7 Salinity mixing pattern in groin segment (Shionoya 2006)

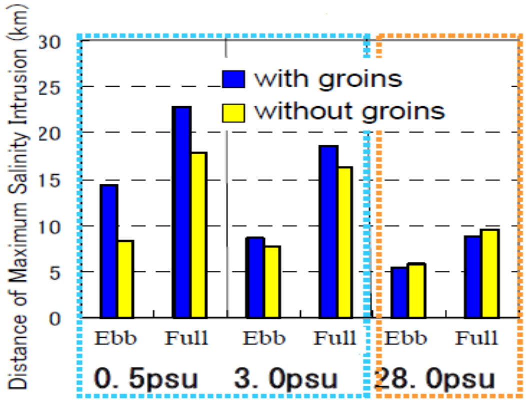


Figure 3.8 The expansion of salinity in groin segment (Shionoya 2006)

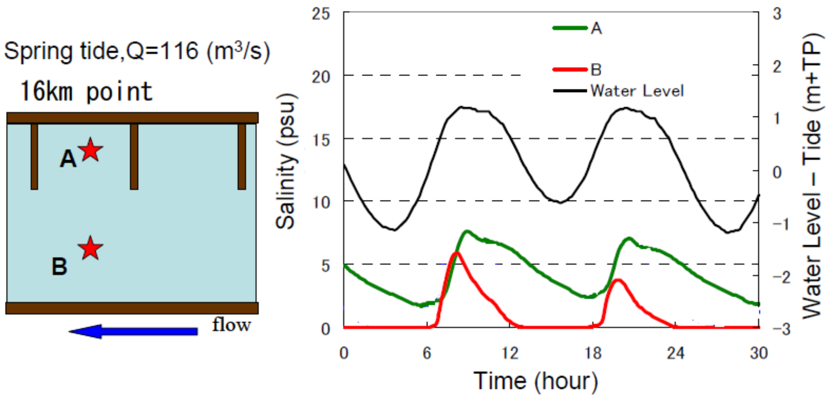


Figure 3.9 Salinity variations inside groin region (Shionoya 2006)

3.4.2 Surface and subsurface flow interactions

Sumi et al. (2002) mentioned that the surface water exchanges not only with the river water but also with the subsurface water. The latter was an important factor controlling the water quality in this area. According to experiment and numerical simulation of subsurface flow, water exchange volume with subsurface water in a tidal period occupied about 9% of the average storage volume of embayment. It suggests that exchange with subsurface water is not negligible to consider the water quality of surface water in embayment.

3.4.3 Dissolved oxygen and water temperature

Takeda et al. (2002) clarified the temporal changes of water temperature in the embayment area (18.8Rkm) in Kiso estuary. The bottom water temperature is 7 ℃ lower than the surface water. It mentioned that strong thermal stratification existed in the center-bottom part of embayment which was caused by low temperature subsurface inflow in ebb tide period. The low temperature water regime less exchanged with main stream flow and caused low dissolve oxygen (DO was less than 4mg/l) condition in the bottom of the embayment.

3.5 Macro benthic community

3.5.1 Characteristics of macrobenthic community

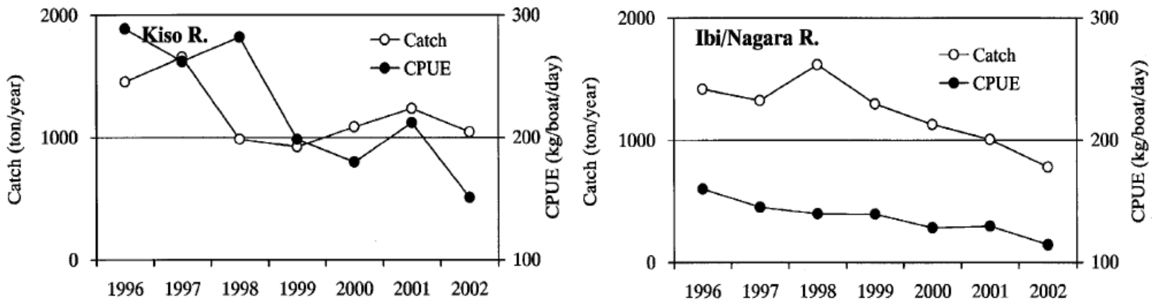
Ito (2013) clarified that the characteristics of habitat environment and structure of benthic communities in riverine estuaries flow into Ise Bay based on Ministry of Land, Infrastructure, Transport and Tourism (MLIT) launched the native census of river environment. Multivariate analysis was carried to quantitatively describe the benthic communities and six groups were classified according to similarity index. The lower reach estuary of Shonai River showed higher percentage of *Capiteliida* resulted from poor water quality (lower values of biochemical/chamical oxygen demand) a large amount of accumulated organic matters. *Polychaeta* was the dominant species in the lower reach estuary of Nagara River, Yahagi River and Miya River. *Chironomidae* occupies an important place in the upper reach of estuaries in Kumozu River, Suzuka River due to a great deal of terrestrial organic matters. In upper reach of Kiso estuary, filter feeder was the dominant species (67±11%); collector gather, scraper, shredder and predator accounted for 29±9%, 2.3±3.6%, 0.85±1.5% and 1.1±1.2% respectively. Kiso estuary is characteristic of higher percentage of mollusk and filter feeder, owing to a great amount of the representative species–*Corbicula japonica*. The author suggested that the highest percentage of filter feeder inhabited in Kiso estuary since the larger river discharge brought a great amount of organic matters as the food sources from upstream; moreover the sand and mud – substrate probably provided suitable environment for bivalves' inhabitation.

Tashiro et al. (2010) found the benthic community showed higher diversity at the intertidal zone in the embayment area than in sub tidal thalweg zone due to higher silt rate and organic matter in intertidal zone. However, *Corbicula japonica* showed higher density in sub tidal thalweg zone comparing to that in inter tidal zone in the area of groins since the limited inundated rate resulted in less opportunities to assimilate food source in the water column. Even though *Corbicula japonica* shows relative higher density in sub tidal zone, the impact of environmental factors on inhabitation of *Corbicula japonica* is scarcely to be discussed.

3.5.2 Distributions of Corbicula bivalves as dominant organisms

In Kiso estuaries, from 1955 to 1980, the annual catch of *Corbicula japonica* sustained about 5000 tons, while which dramatically reduced to 2000~3000tons from1980, ranked second in Japan (Kasai et al., 2006). The shell appearance of *Corbicula fluminea* and *Corbicula leana* are similar and indistinguishable by naked eyes. In the previous studies, it was reported that *Corbicula leana* as the exotic species inhabited in Kiso estuaries (Yamauchi, 2006)

Lower reach of Kiso estuaries is the famous fishery for *Corbicula japonica*. Mizuno (2006) discussed the fluctuations of annual quantity of recruits and the annual catch of *Corbicula japonica* in Kiso estuaries from 1996 to 2002. The annual catch of the bivalve did not tend to decrease, although its fluctuations were marked (Figure 3.10(a)). The significant relationships between annual catch and yearly averaged daily CPUE (an index of the quantity of recruits) indicated that the catch of this bivalve corresponds to annual quantity of recruits. In contrast, in Ibi/Nagara estuary, the annual catch showed decreasing tendency which might have been driven by some of factors not before but after recruitment (Figure 3.10(b)).



(a) (b)

Figure 3.10 Year change of catch and quantity of recruits of *C. japonica* in Kiso estuary (a) and Ibi/Nagara estuary (b)

Nanbu et al. (2005) examined the variations in density of *Corbicula japonica* at different life stages in Kiso estuaries. The highest density of juvenile stage of *Corbicula japonica* was observed in upper brackish zone of Ibi/Nagara estuary (7 - 12Rkm) and Kiso estuary (9 - 12Rkm). It infers that juvenile individuals have higher tolerance to fresh to low saline water than large individuals. However, the results showed that the highest density of large individuals was found in lower reach of Ibi/Nagara estuary (0 - 7Rkm) and upper reach of Kiso estuary (7 - 12Rkm) which resulted from extensive tidal intrusion area in Kiso estuary due to lower riverbed. It also suggested that *Corbicula japonica* have the different requirements for salinity in different life stages.

Sekiguchi (1991) investigated the dynamics of larvae and juveniles of *Corbicula japonica* in lower reach of Kiso estuary (0-5Rkm). The author mentioned that the planktonic larvae of *Corbicula japonica* were taken to shallow water zone, and brought back to the brackish water during the ebb tidal, burrowed in the sediment and sustained the high density in main stream area. It indicated that bivalves could change in their habitats in different life stages, also it confirmed that the key role of shallow water zone for *Corbicula japonica* habitat.

Despite dynamics of the *Corbicula japonica* has been extensive clarified in lower reach of the

Kiso estuary, few studies described the dynamic, distribution and composition of *Corbicula japonica* in the upper reach (groin segment).

3.5.3 Habitat conditions of Corbicula japonica

Asahina (1941) mentioned that the life of *Corbicula japonica* was strictly controlled by salinity. Salinity tolerance capacity of *Corbicula japonica* varied depending on the different river. In Mokoto Lake, *Corbicula japonica* could survive in saline water with 0 to 18psu. In the fishery of Kiso estuary (0-12 Rkm), *Corbicula japonica* could survive when the salinity fluctuated from 3.5psu to 10.5psu, dead in the salinity under 0.3 psu or above 21psu (Tanaka et al. 1984). In the Kiso estuary, the stretch brackish zone in series of groins provided a wider space and longer resident time for relative saline water (0.5-28psu) than that in without groin area (Shionoya, 2006). A series of groins supplied more suitable and stable habitat for *Corbicula japonica* than without groin area from salinity condition perspective.

It was reported that water depth was an important physical factors in impacting *Corbicula japonica* habitat. The investigation of *Corbicula japonica* in Shiji Lake showed that higher density in the water depth less than 4m (Nakamura et al., 1998). The maximum water depth for suitable inhabitatation was 3.5m in Hinuma Lake (Yamazaki et al., 2008). The reason for restriction of water depth was explained for low dissolve oxygen in deeper water depth. The survey in different water depths in Ara River showed that highest density of *Corbicula japonica* lived in the place where the water depth less than 2m. Decreased density occurred when the water depth was about 3m, and almost no individual existed where the water depth reach about 4m. In summary, water depth ranging from 2 to 3m was the suitable condition since at such depths there was less total sulfide and more dissolve oxygen. The sour holes behind the groins might take negative effects to *Corbicula japonica* living due to the deep and lentic area.

The benthic particulate organic matter (BPOM, measured by ash free dry weight (AFDW)) and silt rate were considered as two of the most important substrate environment conditions. BPOM (AFDW) was potential food source for the organisms, and an indicator for the organic pollution. Nakamura (1998) mentioned that higher BPOM (AFDW>14%) and silt rate (>50%) were restrictive substrate conditions for the *Corbicula japonica* in Shiji Lake. Yamazaki et al. (2008) indicated the organic content (AFDW) limited 5%, silt rate under 10% in substrate could be suitable environment for *Corbicula japonica* in Hinuma Lake. In Kiso estuary, Tsubaki et al. (2008) found that the fine suspended particles deposited in the stations in the area with groins due to reduced flow velocity. Tashiro et al. (2010) mentioned that lentic water zone in the area with groins of Kiso estuary was characteristic of high silt rate (10.02%) and AFDW (3.88%). Judging from BPOM (AFDW) and silt rate aspects, generally, it can infer that the series of groins in Kiso estuary probably provide the negative environmental conditions for *Corbicula japonica* than the area without groins.

Maru et al. (1999) examined the behavioral responses of *Corbicula japonica* to different bottom sediment sizes. The sediments included very coarse to coarse sand (500μm~2mm), medium sand (250~500μm), fine to very fine sand (63~250μm) and silt-clay (diameter: 4~63μm). In very coarse to coarse sand and silt-clay sediment tank, upward movements were hindered. However, in medium sand and fine to very fine sand tanks, *Corbicula japonica* moved rapidly in vertical direction.

Sakamoto et al. (1992) mentioned that the surrounding vegetation of habitat influenced the composition of *Corbicula japonica* in Shiji Lake. The authors indicated that *Corbicula japonica* habitat composed by all of growth stages in lakeshore area where amount of *Phragmites australis* developed. It suggested that wetland covered by *Phragmites australis* could be appreciable habitat for *Corbicula japonica*, where the larvae and juveniles could attach the root, the adults could burrow themselves in the sediment among the root. In addition, the *Phragmites australis* were expected to provide diet and dissolved oxygen for the young individuals. It can be inferred that the series of groins in Kiso estuary probably provide the positive environmental conditions for *Corbicula japonica* living due to invasion vegetation in intertidal and subtidal zone of groin-unit.

Food composition and the standing stock directly influenced the inhabitation of benthic communities. Studies of the food source for *Corbicula japonica* were made in the natural estuaries and lakes. Kasai et al. (2005) mentioned that the terrestrial organic matter (TPOM) brought by river flow and utilized as the primary food source for *Corbicula japonica* based on C and N isotopic signatures and concentrations weighted mixing model. Carbon and nitrogen stable isotope ratios of bivalves and particulate organic matters (POMs) indicated that the bivalves in Lake Ogawara and Lake Shinji assimilated autochthonous phytoplankton owing to the longer residence time for water (Kasai et al., 2006).

With open characteristics in area without groins, the water exchanging and material transport are frequently which promoted diverse food sources (POMs from terrestrial and sea side) assembled. However, the two of adjacent groins formed semi-close zone, the peculiar landscape assist in prolonging the resident time for primary productions. It means that the source of particulate organic matters might be completely different in these two landscapes. Therefore, it is necessary to examine the effects of different landscapes caused by groin installation on food sources of *Corbicula japonica*.

3.6 Summary

The effects of groin on flow, sediment distribution have been discussed in chapter1.14. The hydrodynamic regimes, sediment deposition and erosion showed different characteristics between mainstream area and marginal area. The present study focus on the effects of groins installation on habitat of *Corbicula* bivalves in marginal areas (compared the area with groins and the area without groin along the left bank). Due to different shapes, locations of groins and the gravel mining in mainstream area, the landscapes showed obviously different (three representative landscapes) along the longitudinal gradient which reflected different hydraulic conditions, sediment deposition and transportation. Therefore, the influence of environment variables on organisms should be considered not only between with and without groins but also among these three different landscapes in longitudinal gradient. The previous study indicated *Corbicula Japonica* showed higher density in sub tidal zone compared to the in inter tidal zone, thus current study, the effect of environmental factors on inhabitation of *Corbicula japonica* in sub tidal zone are discussed.

In the stagnant zone and local scour holes, the physical-chemical environment are characteristics of fine sediment size, relative higher salinity, high water depth, low oxygen, and low water temperature (Figure 3.11). In the previous study, researchers discussed how the environment variables independently impacted on *Corbicula japonica*. Salinity, water depth, BPOM, silt rate, sediment size and food sources (POM) mentioned above closely linked to inhabitation of *Corbicula japonica*. Some of environmental factors in the area with groin take advantage for *Corbicula japonica* living, such as relative saline water conditions. Some of environmental factors such as the fine sediment size and high water depth probably take disadvantages for *Corbicula japonica* inhabitation. Some of environment conditions impacts are still uncertain such as POMs since we are uncertain about the origin of POMs in groins area and feeding habit for *Corbicula japonica*. We should clarify the relationships among these environmental factors, and discuss how these environmental factors combine together to influence the distributions of *Corbicula japonica*; and which environmental condition was the major factor to impact distribution of bivalves. Therefore, it is necessary to conduct a method to descript the influence of environmental factors on the distribution of *Corbicula japonica* qualitatively and quantitatively (Figure 3.11).

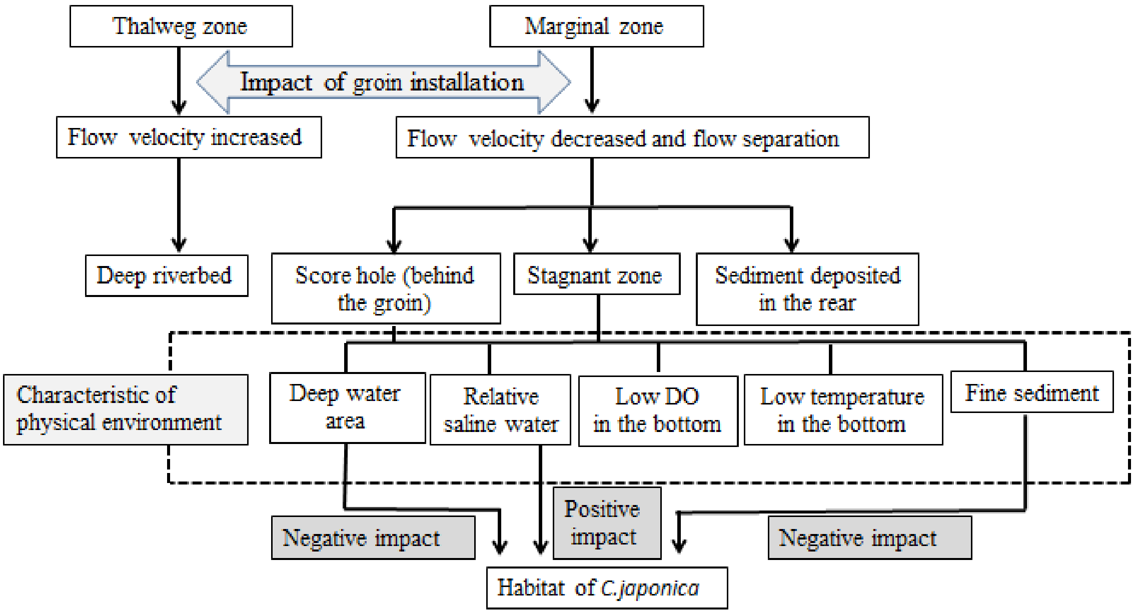


Figure 3.11 The impact of groin on physical environment and *Corbicula japonica*

Reference

Arahina, E., (1941) Ecological studies of clam in Hokkaido, *The Japanese Society of Scientific Fisheries*, 10 (3):143-152 (in Japanese)

Furuhata, H., Ohno, Y., Tashiro, T., Tsubaki, R. and Tsujimoto, T., (2008) Estimation of ecosystem services by brackish bivalve in the Kiso River tidal reach. *Advances in River Engineering* 14: 479-484 (in Japanese).

Hossain, M., M., (1981) Study of river bank stabilization in a bend groin, master degree thesis of *Bangladesh University of engineering*.

Ito,K., (2013) Study on interaction between habitat characteristics and benthic community structure in river estuary, *Bachelor thesis of Nagoya University*(in Japanese).

Katayama,A., Ito,K.,Sasaki,K., Katayama,S., (2013) Carbon and nitrogen sources for the bivalve in Natori River estimated from stable isotope analysis, *Nippon Suisan Gakkaishi* 79 (4):143-152(in Japanese).

Kasai, A. and Nakata, A., (2005)Utilization of terrestrial organic matter by the bivalve *Corbicula japonica* estimated from stable isotope analysis, *Fishery science* 71: 151– 158

Kasai, A., Toyohara, H., Nakata, A., Miura, T., Azuma, N. (2006)Food sources for the bivalve *Corbicula japonica* in the foremost fishing lakes estimated from stable isotope analysis, *Fishery science* 72: 105– 114

Kikumura,T., Yamada,A., Tsujimoto,T., (2001)Embayed topography promoted by local degradation of riverbed behind a groin, *Advances in River Engineering, JSCE, 7*: 327-332(in Japanese).

Kimura, I., Kitamura, T., Sumi, T., Takeda, M., (2002) Cooperative research on morphology evolution and environmental functions of embayed topography formed around spur dikes in the tidal area of Kiso river, *Advances in River Engineering, JSCE*,8: 365-370

Lu, Y.,J., and Zhou, Y.T., (1989) Study on velocity field near redeveloping region behind groin-like Structures, *Journal of Hydrodynamics*, 3.

Maru, K., Yamazaki,M.,Nakai, Z., (2005) Behavioral characteristics of the brackish water bivalve, *Corbicula japonica* Prime to various bottom sediments, *Aquaculture Science*, 53(3) :257-262(in Japanese).

Mizuno,T., Sekiguchi,H., (2006) Catch fluctuations of the brackish water clam Corbicula japonica in Kiso estuaries, central Japan, *The Japanese Society of Fisheries Science*,72(2) :153-159(in Japanese)

Nakamuea, M.,Yasugi, S.,Takahashi, F.,Shinagawa, A.,(1996) Salinity tolerance of the brackish bivalves, *Corbicula japonica* prime, *Aquaculture Science*, 44(1): 23-27(in Japanese).

Nanbu, R., Yokoyama, E., Mizuno,T.,Sekiguchi, H., (2005) Spatial- temporal variations in density of different life stages of a abrachish water clam *Corbicuala japonica* in the Kiso eatusries, central Japan, *Shellfish Research*, 24:1067-1078.

Nanbu, R. and Mizuno, T. (2008) Post-settlement growth and mortality of brackish water clam *Corbicula japonica* in the Kiso estuaries, central Japan, *Fisheries Science*, 74 (6):1254-1268

Nezu, L., Onitsuka, K., Yano, M., (2002) Effect of bed shape on turbulent structure in side-cavity, open- channel flows, *Annual Journal of Hydraulic Engineering, JSCE,*46:559-564 (In Japanese)

Pett, G. E., (1980) Long-term consequences of upstream impoundment. *Environmental Conservation*, 4:325-332.

Sekiguchi, H, Saito, H, Nakao, H. (1991) Spatial and temporal distributions of plankonic and benthic phases of bivalves in a tidal estuary, *Benthos Research*,40: 11-21.

Takeda, M., Kimura, I., Matsuo, N., Yamazaki, Y., (2002) Study on water temperature change and its numerical simulation model in Kiso River wando, *Annual Journal of Hydraulic Engineering, JSCE,*46:1097-1102(In Japanese).

Tanaka,Y.,(1984) Physiological characteristics of *Corbicula japonica* in juveniles stage, *Bulletin of National Research Institute of Aquaculture*, 6: 23-27(In Japanese).

Tashiro,T., Furuhata, H., and Tsujimoto, T. (2010) Benthic animal community in a tidal embayment of the Kiso River, Japan. *Limnology in Tokai Region of Japan*, 43: 61-69(In Japanese).

Tsubaki, R., Furuhata, H. and Tsujimoto, T., (2008) Flow structure on groins during flood event and morphological evolution of topography. *Annual Journal of Hydraulic Engineering, JSCE*, 52: 691-696 (In Japanese).

Shionoya, H., (2007) Characteristics of Salinity Intrusion along Spur Dikes Region in Tidal Reach of the Kiso River, *Bachelor thesis of Nagoya University*(in Japanese).

Sumi, T., Washidu, Y., Tsujimoto, T., A study on water interation between subsurface water in substrate around embayment and surface water in River Kiso, Advances in River Engineering, JSCE,8: 371-376.

Yamaichi,K., (2010) The report for reduction of *Corbicula leana* in upper reach of Nagaka River estuary, Report for Biota Survey in Lower Reach of Nagara River.

Yamazaki,Y.,Suno,N.,Nemoto,T., (2008) Relationship between distribution of the brackish-water Bivalve, Corbicula japonica and sediment environments in Lake Hinuma, *Bulletin of Ibaraki Prefectural Freshwater Fisheries Experimental Station*,41: 25-31.

Yang, C.N., Ishii, N., (1998) The potential of spur dikes in riverside space design, *Advances in River Engineering*, 4:111-116.

Zhang, H., Nakagawa, H., (2008) Scour around spur dyke: recent advances and future researches. Annuals of disaster prevention research institute, *Kyoto University,* 51(B):633-652.

Zhang, H., Zhang, X., Nakagawa, H., Xu, W., Lin, P., Mizutani, H. (2011) Characteristic of grain size distribution in groin field and their environment implications, *Annuals disaster prevention research institute*, *Kyoto University*,54B.

Chapter 4

HABITATS AND FOOD SOURCES OF *CORBICULA* BIVALVES IN KISO RIVER ESTUARY WITH A SERIES OF GROINS

4.1General

Previous researches on the series of groins installation in Kiso Estuary documented that significant differences have been observed on geomorphology, salinity intrusion and other physical environment such as silt rate, water depth between with groins area (right bank) and without groin area (right bank). The landscapes in area with groins were distinguished by wide water area, developing sedimentary area, developed terrestrialization area along the longitudinal gradient from low to up estuary (Kitamura et al., 2001). Relative saline water with mild fluctuation in the area with groins was expected to provide the suitable and stable habitat for brackish organisms (Shionoya 2007). Fine particles often deposited in with groins area result from decreased water flow in back water area. Wide and deepen lentic area was formed due to erosion by water flow and limited of sediment transport from upper zone. However, a few researchers have studied on the responses of biological organisms to changes of the environmental variables and landscapes.

In the groin segment of Kiso estuary, Shionoya (2007) concerned the impact of the variation of salinity in with and without groins on the habitat of *Corbicula bivalves*. It was suggested that higher saline environment in groin-unit provided more extensive and stable habitats for the *Corbicula bivalves* along longitudinal gradient of estuary. Furuhata et al. (2008) compared the effect of the substrate condition along the transverse direction on habitat of *Corbicula bivalves.* It mentioned that higher silt rate (over10%) and high organic content in substrate were the critical factors to limit the survival of *Corbicula japonica*. Tashiro et al. (2010) suggested that periodical inundation and organic content in substrate and silt rate controlled biodiversity along the transverse gradient in a Kiso estuary. However, few findings conduct the impact of multiple environment factors (such as water environment factors, substrate environment factors food conditions) on organisms from both viewpoints of longitudinal and transverse direction in river estuary.

The previous studies of Kiso estuary reported that benthic animals in sub tidal zone were more productive and diverse than those in inter tidal zone (Tashiro et al., 2010, Furuhata et al., 2008). Therefore, it is necessary to examine the influences of spatial shift of environment variables caused by groin construction on *Corbicula* bivalves' habitat in sub tidal zone of the Kiso River with a series of groins. With this aim, the main effects of longitudinal and transverse directions on environment variables, biomass and density of *Corbicula* bivalves would be discussed. Also, we would try to evaluate their biomass and densities with some environment factors.

4.2 Materials and methods

4.2.1Field investigation

In the last chapter, we judged 3 representative landscapes, wide water area (12 R km), developing sedimentary area (17 R km) and developed terrestrialization-area (20 R km). In transverse direction, the landscapes also showed discrepancy in the area with groins, without groin and thalweg. Therefore, we set eight stations along longitudinal and transverse directions in the groin segment as follows (Figure 4.1): St. 1 and 2 were located at riparian zones with and without a series of groins at the 12 R km cross section. St. 3, 4 and 5 were located in sub tidal zone, at the right bank side, thalweg and the left bank side in the cross section of 17 R km, respectively. The uppermost three stations, St. 6, 7 and 8 in the cross section of 20 R km were set in similar positional relations as St. 3, 4 and 5.

In this chapter, I selected salinity and water depth as water environment factors. Additionally, chlorophyll a concentration (Chl. *a*) was also measured since it is not only an indicator for water quality but also for food sources condition (phytoplankton). These environment indicators were logged with salinometer and water depth gauges turbidity meter respectively (COMPACT-CT, -TD and -CLW, JFE Advantech Co., Ltd.). All of the facilities were fixed near the bottom surface. The data were gathered every 5 minutes during a series of tidal motion in all of the stations except those in St. 4 and 7 (Table 4.1). Each of the logged data (salinity, Chl. *a* and water depth) was pooled to get daily average values to conduct the statistics test.

The substrate samples for analyzing organic contents, grain size compositions and *Corbicula* bivalves were collected at all stations (Table 4.1) with the Ekman-Birge grab (area = 0.0225 m^2). In each station, two sets of samples were collected then sealed in glass containers. Suspended particulate organic matter (SPOM) were collected at all stations by plankton-net (mesh size: 60µm) by filtrating a certain volume of water (2000 L), collected SPOM was stored and sealed in a plastic bottle.

Figure 4.1 Location map of Kiso estuary with series of groins, Japan. (source: Google Earth)

Table 4.1 Detail of sampling designs

Site	Features	Items	Method	Sampling date	Location (river km)
St. 1	marge, groins	chlorophyll a, salinity,water depth	logging *in situ*	2012/11/1-11/15	12
		concentration of SPOM, concentration of BPOM, sediment composition, *Corbicula bivalves*		2012/11/14	
St. 2	marge, vegetation	chlorophyll a, salinity,water depth	logging *in situ*	2012/11/1-11/15	
		concentration of SPOM, concentration of BPOM, sediment composition, *Corbicula bivalves*		2012/11/14	
St. 3	marge, groins, vegetation	chlorophyll a, salinity,water depth	logging *in situ*	2012/11/1-11/15	17
		concentration of SPOM, concentration of BPOM, sediment composition, *Corbicula bivalves*		2012/11/14	
St. 4	thalweg	concentration of SPOM, concentration of BPOM, sediment composition, *Corbicula bivalves*	logging *in situ*	2012/11/14	
St. 5	marge, boatslip	chlorophyll a, salinity,water depth	logging in situ	2012/11/1-11/15	
		concentration of SPOM, concentration of BPOM, sediment composition, *Corbicula bivalves*		2012/11/14	
St. 6	marge, groins, vegetation	chlorophyll a, salinity,water depth	logging in situ	2012/11/16-11/30	20
		concentration of SPOM, concentration of BPOM, sediment composition, *Corbicula bivalves*		2012/11/30	
St. 7	thalweg	concentration of SPOM, concentration of BPOM, sediment composition, *Corbicula bivalves*		2012/11/30	
St. 8	marge, boatslip	concentration of SPOM, concentration of BPOM, sediment composition, *Corbicula bivalves*		2012/11/30	

4.2.2 Laboratory procedure

Individuals of *Corbicula japonica* and *Corbicula leana* were identified from each of substrate samples. Then we classified the each of individuals according to their shell size. The shell size could be closed to 7mm for one year old and15mm for two year old. Therefore, according to these standards, species were divided into three groups: less than 7mm, 7mm-15mm, and more than 15mm and the numbers of each group were counted. Tissues were removed from their shell, and washed with distilled water. The tissues were dried at 60 ˚C in the oven for 24 hrs to be a constant weight and weighed. At last, we estimated the biomass and density for each bivalve in all of the stations.

The residual samples were used to extract the benthic particulate organic matters (BPOM). BPOM was divided into two fractions: coarse (CPOM ＞1mm) and fine particulate organic matters (FPOM ＜1mm). Considering that *Corbicula* species only can assimilate the particles from filtration, only BFPOM were counted and analyzed in this research. SPOM and BFPOM were considered as food condition and estimated by ash free dry weight (AFDW) according to Biggs and Karloy (2000). They were separated from samples by GF/B glass-fiber filters (0.47mm Whatman Janan Ltd., Tokyo. pre-combusted at 400 ˚C for 24 hrs), dried with thermostat at 105 ˚C for 24 hrs, and measured to get dry mass. Their AFDW were estimated by weight loss after combustion in a muffle furnace (MPN-310, Shimadzu Rika Co., Ltd.) at 400 ˚C for 4 hrs.

The samples which were removed benthic organisms and BPOM were extracted were undertaken sieve analysis (JIS A 1204). The following parameters of the sediment size distributions were described as: the silt rate, particle size < 75 µm; the median diameter, D50; the coefficient uniformity, $Cu = d_{60} / d_{10}$; and the curvature coefficient, $Cc = d_{30}^2 / d_{10}d_{60}$; where d_x means the representative particle size at the cumulative percentage (x).

4.2.3 Data analysis

In order to compare the spatial distribution of environmental variables and the biological data of *Corbicula* bivalves, two-way ANOVA was utilized to evaluate the main effects of the longitudinal and transverse directions in environmental variables. The collected data were $\log_{10}(Y+1)$ transformed to prevent co-variations with the means if they were not observed either normality or homogeneity of variances. If there were any significant differences in each of the variables due to directional effects, the Scheffe's *F* test was run to confirm where the differences occurred between groups. Furthermore, the principal component analysis (PCA) was utilized to reduce the dimensionality of environmental variables and indicate the approximate change rules of environmental variables in longitudinal or transverse direction.

Pearson correlation analysis was used to analyze the relationship between two of environment variables as well as the relationship between biomass/density of *Corbicula* bivalves and environment variables. As the result, when the Pearson correlation coefficients of the two environmental variables were significant or lager than 0.8, one of a pair of high correlated variables was selected as a representative environmental factor to conduct the multiple regression analysis. Multiple regression analysis was utilized to show relative importance of environmental factors on biomass or density according to establish stepwise regression equation. SPSS 16.0 (SPSS. Inc.) was utilized for these all of statistical analysis.

4.3 Results and discussions

4.3.1Water environment conditions

The two-way ANOVA of salinity values performed a non-significant interaction effect (P = 0.79) between longitudinal and transverse directions. In Figure 4.2 (*a*) shows salinity exhibited significant difference along the longitudinal direction (P < 0.01). Whereas, there was non-significant difference in the transverse direction (P = 0.34). Salinity in the cross section of

12 R km (St.1:2.07±2.62psu, St.2:1.65±1.32psu) showed significantly higher values than those in 17 R km and 20 R km (Table 4.1, Scheffe's *F* test). However, salinity gradient along the longitudinal direction was not clear, such as the between the cross sections of 17 R km (0.29±0.55psu, 0.04±0.05psu) and 20 R km (0.04±0.01psu, 0.02±0.01psu). Although significant differences in salinity were not found along the transverse direction, salinity values were generally higher at stations located with groin (St. 1 and 3) and lower at stations located without groins (St. 2 and 5). Considering that salinity concentration was affected by relatively high tide in the study area. Especially in the area with groin area, the water might be hardly exchanged with that in thalweg zone and the salinity concentration could be conserved near the bottom.

Figure 4.2 (b) shows mean values and standard deviation of Chl. a concentration in each station. A two-way ANOVA of the Chl. *a* concentration revealed significant interaction effect ($P < 0.01$). The effect of longitudinal direction was significant ($P < 0.01$), whereas the effect of transverse direction was not significant ($P = 0.14$). Comparison results of Chl.*a* concentration showed that the values in 12 R km and 17 R km were quite similar ($P = 1.00$, Scheffe's F test). Only the Chl. *a* concentration in St. 6 (at 20 Rkm) was significantly higher than the other transverse directions. We can infer that the Chl. *a* concentration in upper locations with groin was hardly disturbed due to relatively weak tidal effects, which might promote the growth of primary production of phytoplankton.

Figure 4.2 (c) shows mean values and standard deviation of water depth in each station. Water depth was significantly affected by longitudinal and transverse directions ($P < 0.01$). Significant interaction effect was also revealed ($P < 0.01$). Along the longitudinal direction, the differences of water depth between 12Rkm and 17Rkm was not evident ($P = 0.24$). However, significant difference between the cross-sections of 17 R km and 20 R km and between those of 12 R km and 20 R km were found (Scheffe's F test). Water depth was shallower in each of the upper locations (at 20 R km) than those in the lower locations (at 17 R km and 20 R km). Along the transverse direction, the water depth was deeper in the area with groins (St. 1, 3 and 6) than without groins (St. 2, 5 and 8) (P < 0.01).

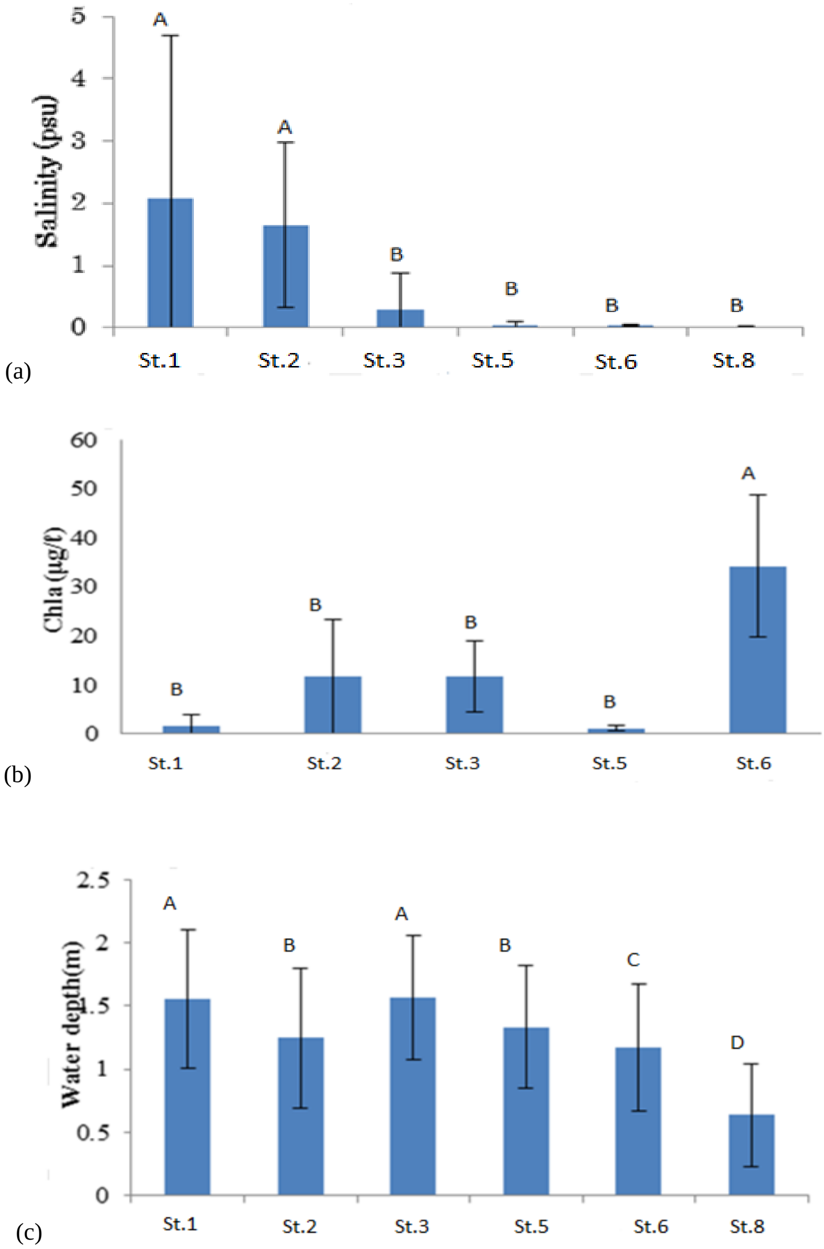


Figure 4.2 Mean values (and standard deviation) of salinity (a), Chl. a concentration (b), water depth (c) in in all of the stations. Where values with different letter are different at significant level (P<0.01)

4.3.2 Substrate and diet conditions for Corbicula bivalves

According to the two-way ANOVA of substrate environment variables (D50, Cu, Cc, silt rate) and diet conditions (BFPOM, SFPOM), they were not significantly affected by the effects of longitudinal and transverse directions (Table 4.2).

Table 4.2 Mean values (and standard deviation) of substrate and diet variables in all of the stations. The same letters in each of the rows are not different at the P = 0.01 significant level (Scheffe's F test)

Cross-section	Station	D50 (mm)	Cu	Cc	Silt rate(%)	SFPOM(AFDW) (g/m^2)	BFPOM(AFDW) (g/m^2)
12Rkm	St.1	0.28	3.29	3.16	2.24	2.59	55.49
	St.2	0.38	5.18	0.63	3.94	7.17	144.11
17Rkm	St.3	0.58	2.04	1.07	0.49	5.51	13.37
	St.4	0.54	2.1	0.94	0.02	1.15	0.63
	St.5	0.58	2.02	1.06	0.02	0.71	0.44
20Rkm	St.6	0.18	2.93	0.8	6.55	2.14	64.5
	St.7	0.57	2.08	1.03	0.03	1.35	0.36
	St.8	0.21	2.54	1.27	1.29	73.91	86.18

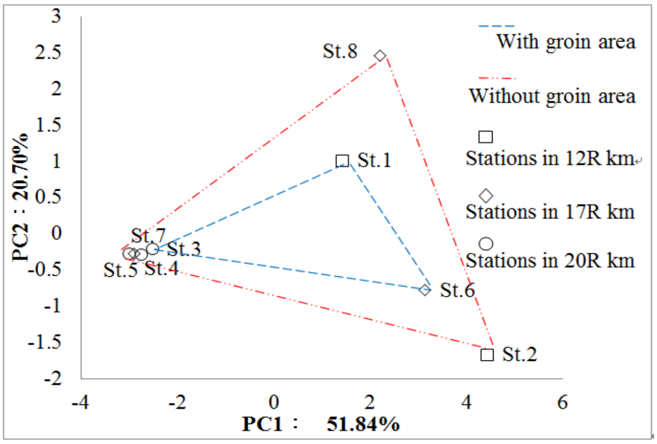


Figure 4. 3 Relationship between the first two principal component scores in the principle component analysis with substrate and diet variables

The scatter plot results using the scores of the first two principal components preserved 51.8 %

(PC1) and 20.7 % (PC2) for the total variance. PC1 was heavily loaded for D_{50} (-0.86), Cu (0.83), silt rate (0.83) and BFPOM (0.95). PC2 was loaded for SPOM (0.77). In Figure 4.3, the environmental variables of 17 R km cross-section (St. 3, 4 and 5) formed a relatively narrow area, indicating that substrate environment variables were more homogeneous than those in 12 R km and 20 R km cross sections. The environment variables in area with groins (St. 1, 3 and 6) built a relative compact cluster, while the environment variables in without groin area (St. 2, 5 and 8) were much more diverse. It is indicated that the differences of substrate and diet conditions among the stations with groins were smaller than those among the stations without groins. Tsubaki et al. (2008) found that in the embayment area flood flow was reduced due to the erosion prevention effects of groins in their 2D flow simulations. We infer that particular terrain and decreased water flow velocity would promote the fine and single suspended particles to deposit in the stations with groins and form relatively homogeneous sediment conditions there. While in the area without groins, substrate and diet environment variables were greatly changeful along longitudinal gradient due to tidal current motion with frequent water exchanges.

4.3.3 The density and biomass of Corbicula bivalves

The biomass and density of these two bivalves in each station was shown in Table 4.3. *Corbicula japonica* was collected from the stations of 12 R km and 17 R km sections. The two-way ANOVA results showed that the biomass and density of *Corbicula japonica* were significantly affected by longitudinal direction ($P < 0.01$) but not significantly affected by transverse direction ($P > 0.01$). Biomass and density showed significantly higher values in 12 R km section than in 17 R km section ($P < 0.01$, Sheffe's F test). *Corbicula leana* was found in all of the stations. The biomass and density of this species did not show significant differences neither along longitudinal nor transverse directions (two-way ANOVA, Table 4.3).

In the longitudinal direction, there was a landward reduction tendency of biomass and density for *Corbicula japonica*, which was correlated with the fluctuation of mean salinity (Table 4.3, Figure 4.2). In contrast, there was no significant difference in the biomass and density of the bivalve along transverse direction which might be corresponded with similar levels of mean of salinity in with groin area and without groin area. *Corbicula leana* is known to be a kind of a freshwater bivalve. However, *Corbicula leana* widely distributed indicated that of the capacity of tolerant of water pollution and low saline water than other mussels (Hwang et al.,2004).

Table 4.3 Mean values of the biomass and density of two bivalves in all of the stations. The same letters in each of the rows are not different at the *P* = 0.01 significant level (Scheffe's *F* test).

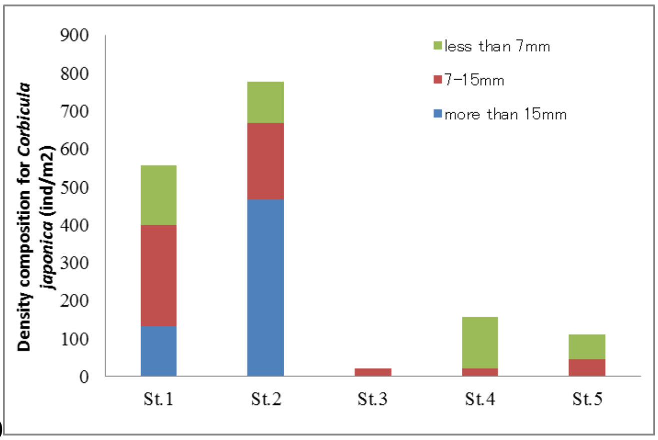
Station	Biomass(g/m^2)		Density(ind./m^2)	
	C. japonica	*C. leana*	*C. japonica*	*C. leana*
St.1	8.35 ^{A}	8.75	555 ^{A}	178
St.2	7.85 ^{A}	3.21	778 ^{A}	422
St.3	0.19^B	3.06	22 ^{B}	622
St.4	0.19^B	0.97	156 ^{B}	200
St.5	0.28^B	1.58	111 ^{B}	133
St.6	0	0.385	0	133
St.7	0	0.335	0	267
St.8	0	1.64	0	156

4.3.4 Density composition for Corbicula bivalves

The number of middle size and large size (> 7mm) of *Corbicula japonica* accounted for 72, 86, and 100 % in St. 1, 2 and 3 respectively, whereas, smaller individuals (< 7mm) occupied 86 and 60 % of the total number in St. 4 and 5 respectively (Figure 4.4(a)). The number of middle size of *Corbicula leana* (7-15 mm) took up 67 to 92 % in all stations, which controlled the density variability (Figure 4.4(b)).

Nemoto et al. (1995, 1996) suggested that generally spawning of *Corbicula japonica* started from late July. After 2 weeks of planktonic life, it settles to the bottom of the lake. In order to avoid from being buried, larvae of *Corbicula japonica* attached the surface of gravel or sand by byssus. However, the muddy and fine sediment substrate was never chosen for the attachment places, since small sediment size increased possibility of suffocate. In the present study, *Corbicula japonica* (less than 7 mm) was abundant (>60% of total) in St. 4 and 5 where silt rate and BPFOM showed the lowest values (Table 4.2, Figure 4.4(a)) which was coincident with previous suggestions (Yamazaki et al., 2008). It is inferred that groin construction probably influence the size compositions of *Corbicula japonica* according to promote the silt rate deposition and organic matters in groin-unit.

(a)



(b)

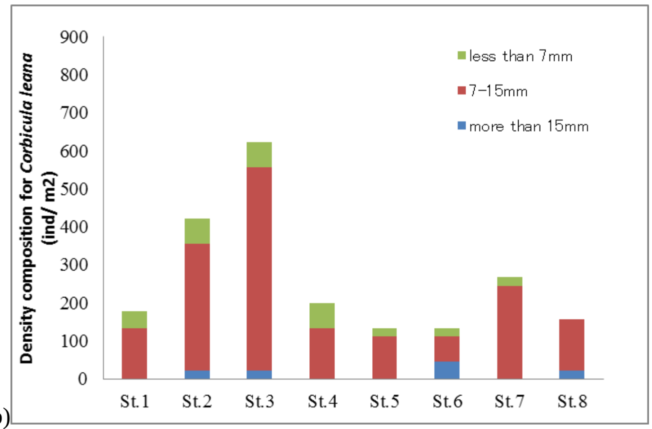


Figure 4.4 Density composition for *Corbicula japonica* (a) and *Corbicula leana* (b) in each station

4.3.5 Relations between biomass / densities and environmental variables

Pearson correlation analysis between each of the bivalves and environmental variables were calculated (Table 4.4). The biomass of *Corbicula japonica* had a significantly positive correlation with the mean of salinity, standard deviation of water depth (water depth (STDEV)) and silt rate. D50 was negatively correlated with the biomass of *Corbicula japonica*. The density of *Corbicula japonica* was significantly positively correlated with the mean of salinity and Cu, which indicate that their higher density occur in higher salinity area and diverse sediment particle size area. Mean of salinity, standard deviation of salinity (salinity (STDEV)) and Cc were positively correlated with biomass of *Corbicula leana.* However, there were not significant correlations between environmental variables and density of *Corbicula leana*.

4.3.6 Multiple regression analysis

It is not sufficient to use a single environment factor to simply describe characteristic of biomass or density for these two species. Thus, it was necessary to conduct the multiple regression analysis and establish equation models between biomass or density and environmental variables accounting for the correlation relationship between environmental variables. D50 and silt rate, salinity and salinity standard deviation, Cu and BPOM showed significant correlation relationship ($p<0.01$), and the correlation coefficient between SPOM and water depth standard deviation showed more than 0.8. Thus, in this research, Chla(x_1), water depth(x_2), water depth standard deviation(x_3), salinity(x_4), D50(x_5), Cu(x_6), and Cc(x_7) should be as the representative factors to do multiple stepwise linear regression analysis. The result showed in Table 4.5. The density of *Corbicula leana* could not be described by regression equation probably due to their random distribution.

Table 4.4 Pearson correlation coefficients between biomass/density of *Corbicula* bivalves and environmental variables (* P <0.05 and ** P <0.01)

	Biomass (C.j)	**Biomass (C.l)**	**Density (C.j)**	**Density (C.l)**	**Chl a (Mean)**	**Chla (STDEV)**	**Salinity (Mean)**	**Salinity (STDEV)**	**Water depth (Mean)**	**Water depth (STDEV)**	**D50**	**Cu**	**Cc**	**Silt rate**	**SPOM (AFDW)**	**BFPOM (AFDW)**
Biomass (C.j)	1	0.756	.949*	-0.071	-0.022	0.311	.986*	0.877	-0.151	.985*	-.967**	0.852	0.505	.915*	0.445	0.831
Biomass (C.l)		1	0.646	0.107	-0.599	-0.485	.851*	.959**	0.532	0.539	-0.232	0.366	.877**	0.047	-0.099	0.247
Density (C.j)			1	0.163	-0.389	-0.01	.923**	0.785	0.313	0.792	-0.166	.868**	0.308	0.28	-0.224	0.639
Density (C.l)				1	-0.063	0.207	0.141	0.129	0.439	0.257	0.424	0.166	-0.234	-0.137	-0.182	0.079
Chl a					1	.890*	-0.425	-0.489	-0.619	-0.214	-0.585	0.08	-0.502	0.832	0.056	0.258
Chl a (STDEV)						1	-0.13	-0.287	-0.621	0.132	-0.537	0.46	-0.581	0.841	0.472	0.613
Salinity							1	.960**	0.441	0.782	-0.127	0.71	0.589	0.143	-0.32	0.463
Salinity (STDEV)								1	0.542	0.715	-0.093	0.493	0.767	0.025	-0.334	0.245
Water depth									1	0.737	0.56	-0.009	0.34	-0.121	-0.677	-0.427
Water depth (STDEV)										1	0.144	0.641	0.231	0.349	-0.809	0.24
D50											1	-0.44	-0.274	-.753*	-0.486	-0.678
Cu												1	0.008	0.616	-0.024	.901**
Cc													1	-0.087	-0.004	-0.042
Silt rate														1	-0.062	0.662
SFPOM (AFDW)															1	0.376
BFPOM (AFDW)																1

Table 4.5 Equations and statistics of stepwise multiple regression between environment variables and biomass / density of bivalves

	stepwise regression equation	R^2	F	P
Biomass (*C. japonica*)	$y=4.196+4.632x_4-3.383x_2$	0.99	176.47	0.06
Biomass (*C. leana*)	$y=-0.48+1.947Ccx_7+1.496x_4$	0.98	24.62	0.04
Density (*C. japonica*)	$y=-280.338+224.336x_4 +123.661x_6$	0.91	25.93	0.01

Regarding the biomass of *Corbicula japonica*, the standardized coefficients of the mean of salinity and water depth showed 1.03 and -0.14 respectively. Salinity was the most significant environmental factor and shown a positive correlation with the biomass, whereas water depth showed negatively response to the biomass. In the estimated equation, there was no substrate environmental factors showed in the stepwise regression equation, which implied that installing of groins did not seriously changed substrate environment, and the slightly substrate environmental change could not significant impact on biomass of *Corbicula japonica* in all of groin segments. Groins impacted biomass of *Corbicula japonica* only by changing the salinity and water depth conditions.

In the present study, the significant differences of biomass of *Corbicula japonica* are found only along longitudinal direction but not obviously along the transverse direction (Table 4.3). Salinity was the predominant factor controlling biomass of *Corbicula japonica*. A decrease in biomass along longitudinal direction was caused by significant reduced salinity condition. In contrast, non-significant difference along the cross-section was found because dominant factors (salinity) showed similar levels in with and without groin area and water depth did not play a dominant role (standardized coefficients:-0.14). Therefore, we infer that groin did not significantly impact biomass of *Corbicula japonica*.

The standardized coefficients of the mean of salinity and Cu for describing density of

Corbicula japonica showed 0.62 and 0.43 respectively, which indicated that they positively affected on *Corbicula japonica* density. Moreover the salinity was relatively more efficient. Therefore, the density of *Corbicula japonica* showed significant higher values in lower reach than upper reach (17Rkm).

There was a significant correlation ($R^2 = 0.90$, $P < 0.01$, Table 4.5) between Cu and BFPOM. It was demonstrated that BFPOM might be an environmental variable positively affecting density of *Corbicula japonica*. Although the previous studies suggested that the AFDW of substrate component negatively controlled *Corbicula japonica* distribution, the present research indicated that BFPOM (AFDW) might be considered as a critical substrate condition and positively impacted their distributions when it ranged from 0.44 to 144.11g/m^2.

The standardized coefficients of Cc and the mean of salinity for describing biomass of *Corbicula leana* showed 0.64 and 0.45 respectively, which indicated that both of them were positively correlated with the biomass of *Corbicula leana*; the impact of Cc on the biomass was more important than salinity. Therefore, numerous *Corbicula leana* probably occurred in well-graded sediment area or lower reach of the estuary such as St.1. Even though *Corbicula leana* is known as a kind of a freshwater bivalve, in present study, it inferred that the salinity could positively affect the biomass of *Corbicula leana* when it fluctuated during lower range (0.04-2.07psu).

SPOM (AFDW) collected in each station did not show significant correlation coefficients with biomass and density for these two bivalves (Table 4.5). The higher particulate organic matter did not correspond with higher biomass and density. SPOM might not be controlling factors for the distribution of *Corbicula* bivalves. Kasai et al. pointed out terrestrial particulate organic matter was the primary food source for *Corbicula japonica*, based on stable isotope of carbon and nitrogen analysis (Kasai et al. 2006). In this chapter study, the SPOM in situ was not an essential diet for these two bivalves judging from Pearson correlation analysis. The organic matter derived from vegetation along the riparian or upstream (terrestrial organism) should be considered.

4.4 Summary

This research conducted to clarify the influence of environment variations (including water physical environment factors, substrate factors and diet conditions) caused by a series of groins installation on biomass and density of *Corbicula* bivalves in the Kiso River (12 - 20 R km).

The concluded shows as below:

1. Water environment variables (salinity and water depth) showed significant higher values in low reach of estuary. Salinity exhibited similar values in the area with groins and without groins area. However, water depth showed significantly different between with groin and without groin area. It indicated that groin took great influence in changing the topography of riverbed and caused a larger deep water area, but less influence in salinity.

2. Substrate and diet variables did not show significant different among various landscapes. Diverse sediment size appeared in 12Rkm and 20Rkm cross-sections. Substrate conditions showed homogenous characteristics through the area with groins compare to those in the area without groins by considering slowly water flow promoted the fine and single suspended particles to deposit in the stations with groins.

3. According to multiple regression analysis, the biomass and density of *Corbicula japonica* were positively affected by salinity. Water depth has a negative effect on their biomass, whereas diverse distributions of substrate have a positive effect on their density. Along the transverse direction, there was no obvious difference in both biomass and density of *Corbicula japonica* in sub tidal zones. Groin installation has a small impact on biomass and density due to similar

levels of salinity and less important factor water depth (standardized coefficients:-0.14). Along the longitudinal direction, the increasing trend of the biomass and density are attributed to increased predominant factors of salinity level.

4. According to multiple regression analysis, the biomass of *Corbicula leana* did not varied depending on the transverse and longitudinal directions due to the irregular changes of Cc and less effect of salinity. Cc plays the most important role in supporting higher biomass of *Corbicula leana*.

5. Groins installation might induce differences composition of *Corbicula japonica*. More than 60% of *Corbicula japonica* individual was composed by the smaller size individuals in without groin and thalweg which might result from lowest silt rate and BFPOM.

6. Depending on Pearson correlation analysis, the SPOM in situ was not an essential diet for these two bivalves. Determining the food sources is an important problem in the next chapter.

Reference

Biggs, B. J. F. and Kilroy, C. (2000) Stream Periphyton Monitoring Manual. New Zealand Institute Water and Atmosphere for Ministry for the Environment, Christchurch, New Zealand, http://www.niwa.co.nz/sites/default/files/import/attachments/peri_complete.pdf

Furuhata, H. Kohno, S. Tashiro, T.Tsujimoto, T., (2008)Habitat characteristic of Corbicula japonica in sand bar of the Kiso iver tidal reach, *Advancesin River Engineering* 14: 479-484(In Japanese).

Hwang, S.J., Kim, H.S., Shin, J.K., Oh, J.M. and Kong, D.S., (2004) Grazing effects of a freshwater bivalve (*Corbicula leana* Prime) and large zooplankton on phytoplankton communities in two Korean lakes, *Hydrobiologia* 515: 161-179.

Kasai, A., Toyohara, H., Nakata, A., Miura, T., Azuma, N., (2006)Food sources for the bivalve *Corbicula japonica* in the foremost fishing lakes estimated from stable isotope analysis, *Fishery science* 72: 105-114.

Nemoto, T., (1995)Research of Corbicula japonica in Lake Hinuma -A study on variation of the number of juvenile individuals, Bulletin of Ibaraki Prefectural Freshwater Fisheries Experimental Station, 31, 66-82(In Japanese).

Nemoto, T., (1996) Research of Corbicula japonica in Lake Hinuma -Seasonal changes of D type juvenile individuals, *Bulletin of Ibaraki Prefectural Freshwater Fisheries Experimental Station*, 32, 8-20(In Japanese).

Shionoya, H., (2007) Characteristics of Salinity Intrusion along Spur Dikes Region in Tidal Reach of the Kiso River, *Bachelor thesis of Nagoya University* (In Japanese).

Tashiro,T., Furuhata, H., and Tsujimoto, T., (2010) Benthic animal community in a tidal embayment of the Kiso River, Japan. *Limnology in Tokai Region of Japan*, 43: 61-69 (In Japanese).

Tsubaki, R. Furuhata, H. and Tsujimoto, T., (2008) Flow structure on groins during flood event and morphological evolution of topography, *Annual Journal of Hydraulic Engineering, JSCE*. 52: 691-696 (In Japanese).

Chapter 5

FOOD SOURCE VARIATIONS IN DIFFERENT LANDSCAPES FOR *CORBICULA* BIVALVES

5.1General

Landscape changes had a major impact on hydrological and sediment connectivity in the river (Veerle Vanacker et al., 2005) and involving the particulate organic matters transport and nitrogen cycling (Pinay et al., 2002). The primary production and particulate organic matter are the critical food sources in fluvial ecosystem. Thus, landscape change would impact food sources and the whole food web in some extent.

Corbicula japonica is commonly found in brackish rivers or lakes, while *Corbicula leana* is considered as a freshwater species. *Corbicula japonica* and *leana* have been widely inhabited in Kiso estuary (Nanbu et al., 2004). The study of Ogawara and Shinji brackish lakes showed that these bivalves mainly fed on autochthonous phytoplankton characteristic by high productivities (Kasai et al., 2006). Kasai and Nakata (2005) indicated that *Corbicula japonica* in river estuary mainly fed on the terrestrial organic matters, using carbon and nitrogen stable isotope ratios. However, there are few food sources in groin segment, and the food sources for two *Corbicula* species in the same location have never been discussed. It was also uncertain whether both of them will shift their food sources with landscapes in their different growing stages.

The environments in Kiso estuary are characterized by the complex variations in landscapes since series of groins installed along the one side of the bank. In the last chapter, we found that SPOM (AFDW) in situ did not show significant correlation with biomass and densities of these two bivalves. It means that food sources are still uncertain in these complex landscapes. Therefore, in present study, by measuring the stable isotopes of *Corbicula japonica* and *leana* in Kiso estuary, we conduct to clarify the effect of different landscapes caused by groin installation on their food sources variations.

5.2 Materials and methods

5.2.1Field investigation

In order to examine food source variation in different landscapes, we selected the three stations (St. R, St. M and St. L) across17 R km cross-section as the objectives (Figure 5.1 and 5.2). The details of the sampling designs are listed in Table 5.1. Potential food sources (SPOMs) were not only collected from 17 R km but also from its upstream (St. U1, U2, U3 and U4) and downstream (St. D1 and D2) area (Table5.1).

The facilities to collect salinity, chlorophyll a concentration (Chl. a) data were as the same as in last the chapter. The substrate samples (analyzing organic contents and *Corbicula* bivalves) and SPOM samples were collected by two replicates, and the methods for collection referred to the last chapter.

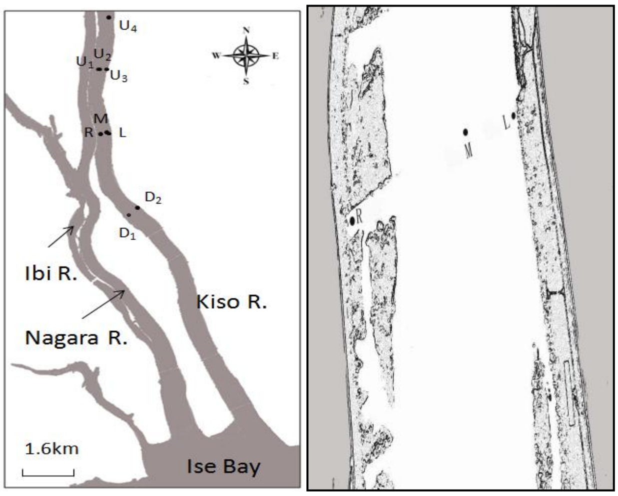


Figure 5.1 Study locations of Kiso River estuary.

Figure 5.2 Photographs of sampling stations in typical landscapes

(upper left: St. R, upper right: St. L, lower left: St. M and lower right: St. D2)

Table5.1 Detail of sampling designs

Site	Features	Items	Method	Sampling date	Location (river km)
St. R	marge, groins	chlorophyll a and salinity	logging *in situ*	2012/11/1-11/15	17
		ash free dry mass, carbon and nitrogen (CN) stable isotope ratio of SPOMs	analyzing *in vivo*	2012/11/14	
St. L	marge, boatslip	density, size composition, CN stable isotope ratio of *Corbicula* bivalves	analyzing *in vivo*	2012/11/14	
St. M	thalweg, bar	ash free dry mass, carbon and nitrogen (CN) stable isotope ratio of SPOMs	analyzing *in vivo*	2012/11/14	
		density, size composition, CN stable isotope ratio of *Corbicula* bivalves	analyzing *in vivo*	2012/11/14	
St. U1	marge, groins, vegetation	chlorophyll a and salinity	logging *in situ*	2012/11/1-11/15	20
St. U2	thalweg	ash free dry mass, carbon and nitrogen (CN) stable isotope ratio of SPOMs	analyzing *in vivo*	2012/10/4	
St. U3	marge, boatslip	ash free dry mass, carbon and nitrogen (CN) stable isotope ratio of SPOMs	analyzing *in vivo*	2012/10/4	
St. U4	marge, vegetation	ash free dry mass, carbon and nitrogen (CN) stable isotope ratio of SPOMs	analyzing *in vivo*	2012/6/7	24
St. D1	marge, groins	chlorophyll a and salinity	logging *in situ*	2012/11/1-11/15	12
St. D2	marge, vegetation	ash free dry mass, carbon and nitrogen (CN) stable isotope ratio of SPOMs	analyzing *in vivo*	2012/11/1	

5.2.2Laboratory procedure

The treatment process for benthic organisms was the same with the last chapter. To measure the stable isotope ratios of carbon and nitrogen of these individuals, their tissues were picked from several bivalves and dried and removed fat by according to the conventional method (Yamada et al. 2014), then were analyzed with the Flashy EA1112-DELTAV ADVANTAGE ConFloⅣ System (EA-IRMS) (Thermo Fisher Scientific Inc.).

Sampled SPOMs were divided into two parts. One was used to estimate their concentrations by ash free dry weight (AFDW) following the method in the last chapter. The other was measured for stable isotope ratios of carbon and nitrogen with same method for the bivalves samples (Yamada et al. 2014). Two replicates samples were collected and mixed together to measure the stable isotope ratios. $\delta^{13}C$ and $\delta^{15}N$ are expressed by the standard a notation as follows:

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

where X is either ^{13}C or ^{15}N, and R is $^{13}C/^{12}C$ for carbon and $^{15}N/^{14}N$ for nitrogen. Pee Dee Belemnite and atmospheric nitrogen were used as the isotope standards for carbon and nitrogen, respectively. Also, we sampled leave of typical terrestrial plants such as reeds and willows in each of the stations, to measure their stable isotope ratios. Moreover, the Cluster analysis (with Euclidean distance and Ward's method) was conducted to categorize the SPOM variations with stable isotope ratios.

5.2.3 Data analysis

Student's t test was conducted to determine whether there were significant differences in physical items between Sts. R and L. Two-way analyses of variance (ANOVA) were used to test the effects of the size (L, M and S) and transverse location (St. R, St. M and St. L) on the density of each of the bivalves. If there were any significant differences in each of the variables, the Scheffe's F tests were run to confirm where the differences occurred between groups.

The IsoSource (ver. 1.3.1) software (Phillips et al. 2003) was used to determine the percentage of contribution of each of the organic matters to the diet of bivalve using both $\delta^{13}C$ and $\delta^{15}N$. All possible combinations of each source contribution (0-100%) were examined by small increments (1-2%). The incremental parameter was set to 1%, and the tolerance parameter was initially set at 0.1 %. If the mixture isotope values were out of bounds, we increased the tolerance parameter by 0.1 % until it reached (Shin et al.2013). In adopting these software, we set the hypothetical food source by giving presumptive 0.8‰ trophic shift in the $\delta^{13}C$ and 3‰ shift in the $\delta^{13}N$ (Hansson et al.1997) between potential food sources and the bivalves.

5.3RESULTS AND DISSCUSSIONS

5.3.1Physical environment conditions

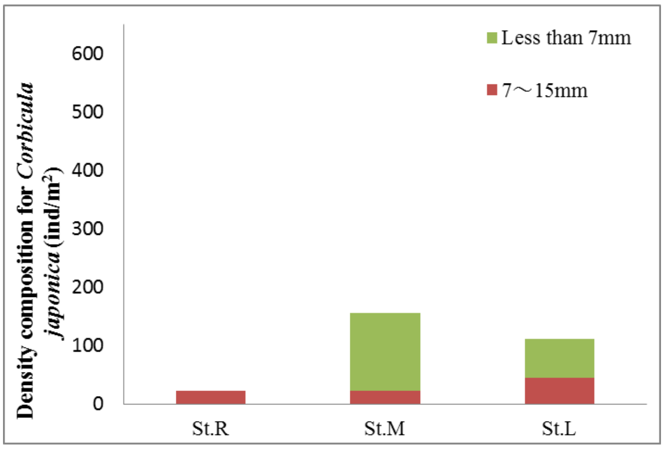
Table 5.2 shows the concentrations of chlorophyll a, SPOM and salinity in each of the station. According to the Student's t-test results, chlorophyll a and salinity showed significantly higher values in St. R compare to those in St. L (P < 0.05). The SPOM at St. R was also somehow higher than that at St. L. It indicated that habitat environment in St. R is considered to be relatively lentic while that in St. L is considered to be lotic, which are contrasting landscapes due to the series of groins.

Table 5.2 Concentrations of chlorophyll a, SPOM and salinity (Chl. a, salinity: n＝13;SPOM: n＝2)

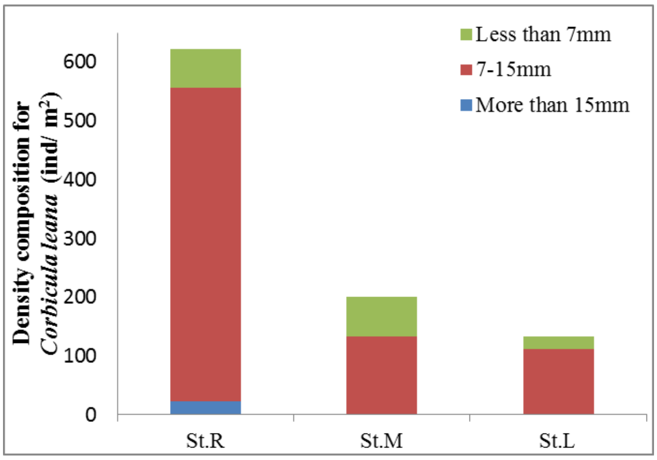
	St. R	St. M	St. L
Chl. a (μg/L)	11.72±7.28	-	1.13±0.58
SPOM (mg/L)	5.51	1.15	0.71
Salinity (PSU)	0.29±0.55	-	0.04±0.05

5.3.2 Distributions of *Corbicula* bivalves

Figure 5.3 shows the density distributions with the three size classes of the *Corbicula japonica* (a) and *leana* (b) in each of the stations. Two-way ANOVA results showed that neither size nor the locations significantly influenced density of the bivalves (P > 0.01). The total density of *Corbicula japonica* showed relatively lower value in St. R than the other stations. In contrast, *Corbicula leana* showed much higher density in St. R. Additionally, the *Corbicula japonica* individuals in St. R were completely composed by the M size ones, however, in Sts. M and L, those were mainly occupied by the S size one. About the *Corbicula leana* individuals, their M size ones were main components in each of the station. The density of both of the bivalves showed converse result along the transverse direction.



(*a*)



(*b*)

Figure 5.3 Density distributions with three size classes of *C.japonica*(*a*) and *C.leana* (*b*) in Sts. R, M and L.

5.3.3 Stable isotopic signatures of suspended organic matters

Figure 5.4 shows the δ^{13}C and δ^{15}N plots of SPOMs in all of the collected samplings. The δ^{13}C ranged from -27.76 to 24.24 ‰, showing a systematic decrease from seaward to landward except some of irregular point such as St. D2 (-27.15‰). In transverse direction, the δ^{13}C in the thalweg area (Sts. M and U2), showed relatively higher values than with and without groins area of the same cross-section. In the previous study, marine POM showed significantly higher value of δ^{13}C than river and terrestrial POMs. Mixing process of fresh water and adjacent marine water resulted in the δ^{13}C of POMs is gradually decreasing and close to TPOM along the landward (Kasai et al. 2004). However, in the current study, considering the different terrain and vegetation distribution between the areas with and without groins, the δ^{13}C values of SPOMs did not change regularly following the salinity concentration as shown in the conventional report (Kasai et al. 2004). Additionally, the SPOMs showed a wide range of δ^{15}N values from 1.70‰ to 5.01‰.

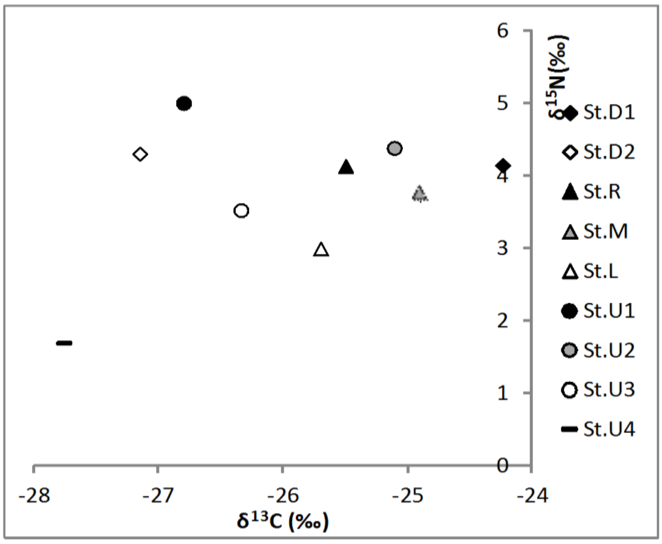


Figure 5.4 δ^{13}C and δ^{15}N plots of potential food sources (SPOMs), collected from Sts. R, M and L; upstream Sts. U1, 2, 3, 4 and downstream Sts. D1, 2.

Table 5.3 shows the results of classification by using the cluster analysis with the carbon and nitrogen stable isotope ratios. The sampled SPOMs were categorized into 4 groups based on Euclidean distance. The group I displayed lower δ^{13}C values (-27.15~-26.8‰) and more enriched δ^{15}N values (4.31-5.01‰) than the other groups. They were similar with the collected samples of reed, *P. australis* (δ^{13}C=-27.29‰, δ^{15}N=4.95‰). It means that SPOM of group I might derive from detritus of autochthonous terrestrial vegetation. Both of two samples of the type II were collected from the stations near to the left bank without groins (Sts. L and U3), which showed intermediate values of δ^{13}C (-26.34~-25.70‰) and relatively lower values of δ^{15}N (3.00~3.53‰).

The group III was composed of the data from the area with groins (Sts. R and D1) and thalweg area (Sts. M and U2). Their higher salinity values (Table 5.2) and relatively enriched values of $\delta^{13}C$ suggested that the type III was mainly affected by high tide intrusion. The $\delta^{13}C$-enriched marine organic matter brought by the tidal current easily intruded or reserved in these. The type IV collected from the upper estuary (St. U4 in 24R km) showed the lowest values of $\delta^{13}C$ (-27.76‰) and $\delta^{15}N$ (1.7‰), which indicated that it was strongly influenced by terrestrial particulate organic matter (TPOM) (Kasai et al. 2004).

T**able 5.3** Cluster result for SPOM by Euclidean Distance depending on $\delta^{13}C$ and $\delta^{15}N$ values

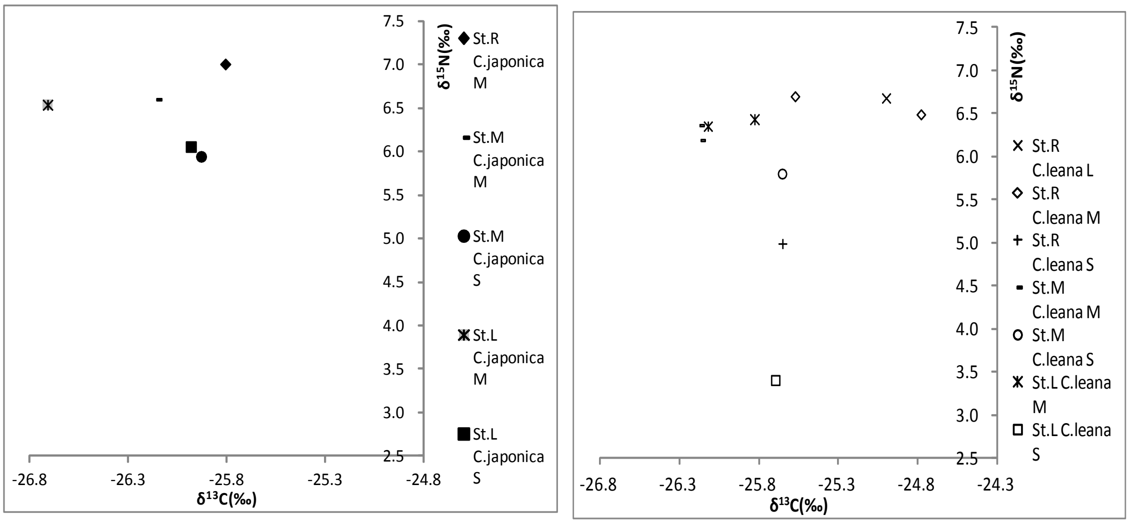
Group	I	II	III	IV
station	St.D2,St.U1	St.L, St.U3	St.D1,St.R, St.M, St.U2	St.U4
$\delta^{13}C$ variation(‰)	-27.15~-26.8	-26.34~-25.70	-25.50~-24.24	-27.76
$\delta^{15}N$ variation(‰)	4.31~5.01	3.00~3.53	3.79~4.39	1.7

According to the result of these classifications, the SPOM collected from Sts. D2, L and U4 were selected as the representative end members of group of I, II and IV, respectively. Although Sts. R and M belonged to the same group III, the SPOMs collected from Sts. R or M were selected as the representative end members of type of III according to the proximity principle. In the food source analysis below, these end members are considered to be used for the estimation with the IsoSource (Phillips et al.2003).

5.3.4 Stable isotopic signatures of Corbicula bivalves

Figure 5.5 shows the $\delta^{13}C$ and $\delta^{15}N$ plots of tissues of *Corbicula japonica* and *leana* in each of the stations. The $\delta^{13}C$ of *Corbicula japonica* ranged from -26.7‰ to -25.81‰ (Figure 5.5(a)), while those of *Corbicula leana* showed relatively higher values ranged from -26.2‰ to -24.8‰

(Figure 5.5(b)). The δ^{15}N of *Corbicula japonica* showed narrow range (5.94 to 7.00‰) (Figure 5.5(a)), while *Corbicula leana* showed wider and relatively lower values (3.41 to 6.68‰) (Figure 5.5(b)). The characteristic of isotope values for these two bivalves suggested that *Corbicula japonica* preferred the organic matter with depleted-δ^{13}C and more enriched-δ^{15}N SPOM as the food source compared to *Corbicula leana* in this study area.

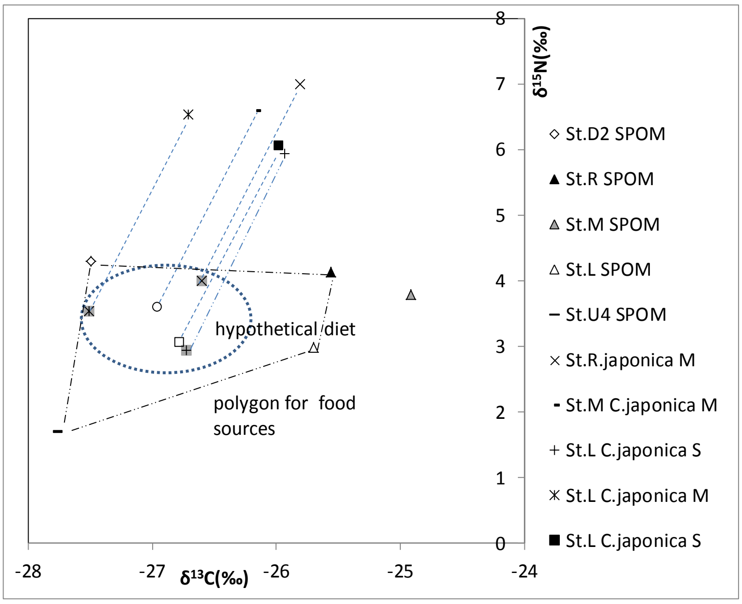


(a) (b)

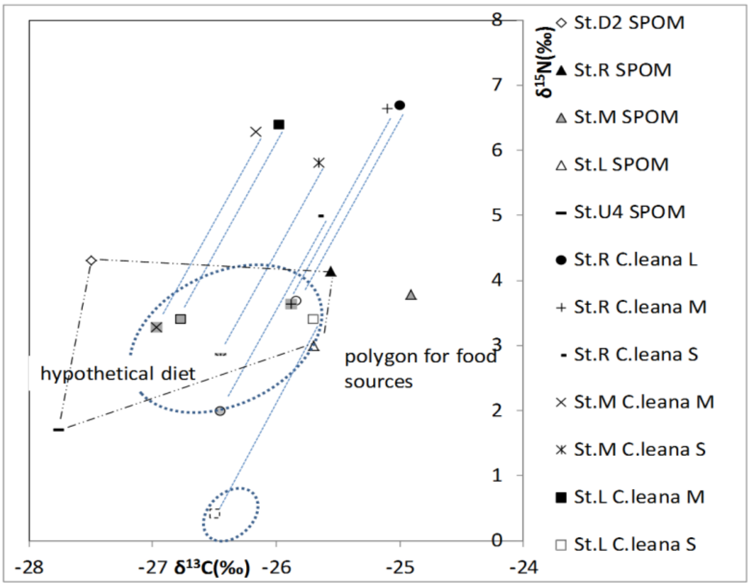
Figure 5.5 δ^{13}C and δ^{15}N plots of *C. japonica* (a) and *leana* (b) with size classes in Sts. R, M and L

Figure 5.6 (a) shows that the δ^{13}C and δ^{15}N plots of SPOM end members and *Corbicula japonica* individuals with these size variations. Both of the hypothetical diets of each of the bivalves and the food sources polygon with the end members are drawn in this figure. Their isotope signatures of hypothetical diets were quite different from those of SPOMs in the same location. It suggested that the neighbor SPOM cannot always be used as the essential food source for *Corbicula japonica* in each of the locations. As the isotope signatures of bivalves decreasing from St. R, their hypothetical diets were closer to SPOM of St.D2 and St.U4 indicated the contributions of these two food sources increased from Sts. R to L. We also can infer that SPOMs of Sts. D2 and U4 are the necessary diets, because if one of the SPOM of Sts. D2 and U4 were absent, almost all of the isotope signatures of hypothetical diet would outside the convex polygon boundary of the food sources (Shin et al., 2013). The S size *Corbicula japonica* individuals showed relatively lower $\delta^{15}N$ values than the larger individuals, which implied that they might take relatively depleted-$\delta^{15}N$ SPOM was the main diet.

Figure 5.6 (b) shows that the $\delta^{13}C$ and $\delta^{15}N$ plots of SPOM end members and *Corbicula leana* with size variations. Both of their hypothetical diets and food source polygon with the end members are drawn in the same figure. The $\delta^{13}C$ and $\delta^{15}N$ of L and M size individuals of *Corbicula leana* found in with groin area (St.R) showed the most enriched values ($\delta^{13}C$= -25.0‰, $\delta^{15}N$=6.68‰; $\delta^{13}C$= -25.1‰, $\delta^{15}N$=6.60‰, respectively). The isotope signatures of hypothetical diet of L and M size individuals (Figure 5.6 (b), ca. $\delta^{13}C$= -25.8‰, $\delta^{15}N$=3.64‰) exhibited similar values to St. R (in situ), which suggests that the neighbor SPOM take largest contribution to their food composition. While the $\delta^{13}C$ and $\delta^{15}N$ of hypothetical diets for M size individuals in Sts. L and M were closer to the SPOMs in Sts. U4 and D2, which indicated they were the important food sources. Additionally, the isotope signatures of hypothetical diets for S size of *Corbicula leana* displayed similar values of $\delta^{13}C$ (ca.-26.3‰) in each of the stations, while the $\delta^{15}N$ (0.4-2.80‰) was relatively lower than the larger individuals (3.40-3.68‰). The plots of hypothetical diets indicated that *Corbicula leana* might shift the food sources depending on growth stages; we could not find the food sources for S size individuals in the present study because points of their isotope signatures were out of food sources of polygon.



(a)

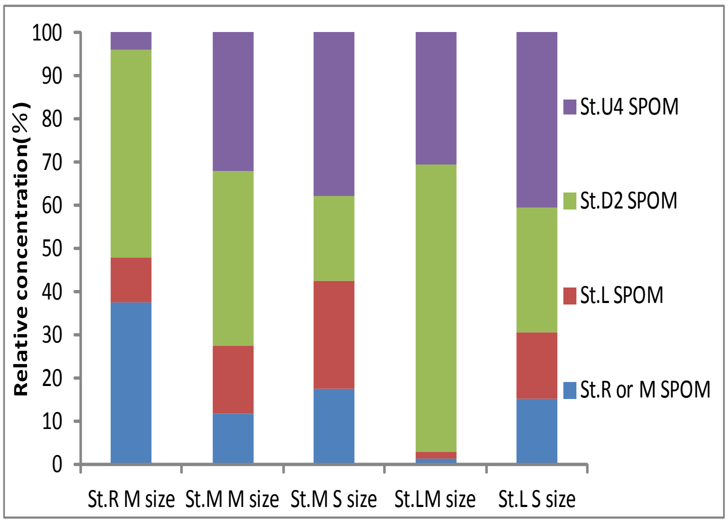


(b)

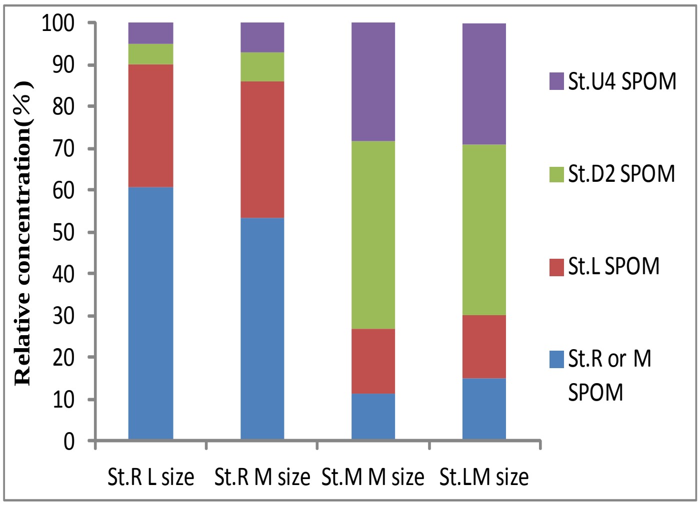
Figure 5.6 $\delta^{13}C$ and $\delta^{15}N$ plots of SPOM end members *C. japonica*(a) and *C. leana* (b) with size variations. Hypothetical diets are put a ring around, and connected to each of the bivalves with dotted lines. Food source polygon with the end members are drawn by broken lines.

5.3.5Food sources contribution

Figure 5.7 shows that the food compositions (%) of the SPOM end members for *Corbicula* *japonica* (a) and *leana* (b) in each of the stations. The M size of *Corbicula japonica*, the SPOM from St. D2 accounted for the largest contribution of the food sources (40.4 ~ 66.6%), followed by the SPOM from St. U4 (4.2 ~ 32.1%) in each of the station. The contributions of these two food sources increased from the area with groins (St. R) to that without groins (St. L). Great utilization of $\delta^{13}C$-depleted SPOM (SPOM of Sts.D2 and U4) in each stations indicated that the adult of *C. japonica* might be a selective filter feeder, mainly depending on TPOM. In the area with groins (St. R), water exchange was reduced due to the blocking effect of groins (Tsubaki et al. 2008), which limited the material transport between the area with groins (St. R) and thalweg zone (St. M). Consequently, their preferable food sources could be restricted to the semi-closed embayment area (St. R), while in the area without groins (St. L), water exchanging supplied the preferable food sources. Additionally, the highest concentration of neighbor SPOM (5.51mg/L, Table 5.2) corresponded to the lowest density of *Corbicula japonica* bivalves (22.2ind/m^2, Figure 5.3) in St. R; the lowest concentration of SPOM in Sts. M and L (1.15 and 0.71mg/L respectively, Table 5.2) corresponded to the highest density of *Corbicula japonica* bivalves (155.5ind/m^2, 111.1ind/m^2, Figure 5.3). It also proved that a large amount of $\delta^{13}C$-enriched SPOM in St. R might not be as an ideal food source for *Corbicula japonica*. The SPOM with depleted $\delta^{13}C$ value might be the potential food source for *Corbicula japonica* such as terrestrial organic matter. The capacity of digestion of terrigenous organic matter was reported due to cellulose and hemicellulase activities of the bivalve (Sakamoto et al., 2009a), and in particular, endogenous cellulase and xylanase genes have been identified (Sakamoto et al., 2009b).



(a)



(b)

Figure 5.7 Food compositions (%) of the SPOM end members for *C. japonica* (a) and *leana* (b) in each of the stations

Food sources for the S size individuals of *Corbicula japonica* in Sts. M and L relatively lower utilization of SPOM from St. D2 (ca.24%) and higher those from St. U4 (ca.39%), also smaller size of *Corbicula japonica* tended to digest and assimilate the food sources with relatively lower $\delta^{15}N$. It was supposed that the smaller size of *Corbicula japonica* might have weak capacity in assimilating the SPOM derived from nitrogen-polluted water since increased $\delta^{15}N$ value was found in excessive richness of nitrogen loaded water (Hansson et al.1997).

Regarding the *Corbicula leana,* in St. R, the L and M size individuals utilized food sources of similar compositions, mainly depending on the neighbor SPOM which accounted for 60.5 and 53.2 % respectively. The M size of *Corbicula leana* in Sts. M and L showed similar food compositions, mainly depending on the SPOM from St.D2 (44.6%, 40.9% respectively) and St.U4 (28.4%, 29% respectively). The adult *Corbicula leana* completely shifted food compositions between the area with groins (St. R) and the one without groins (St. L), which indicated that adult *Corbicula leana* might be an opportunistic filter feeder. In the area with groins (St. R), dense Chl.a with neighbor abundant SPOM (11.72 µg/L, 5.51 mg/L, Table 5.2) were trapped in this kind of semi-closed area. In this situation, the utilization of the neighbor SPOM was higher. A large quantity of food sources in situ supported approximately 3 times of individuals in Sts. L or M (Figure 5.3). However, in the area without groins (St. L), due to the bare and relatively open terrain, the primary production might be lower. The Chl. a and SPOM (1.13µg/L, 0.71mg/L， Table 5.2) were insufficient and could not provide enough diet. Under this situation, individuals of *Corbicula leana* decreased compared with St. R (Figure 5.3). However, bare terrain also promoted water mixing process between river flow and intruded marine and made food sources diverse. The conventional study concluded that *Corbicula leana* was a fresh water bivalve and selected TPOM as the food source (Hwang et al., 2004). However, in the present research, the adult *Corbicula leana* was considered as an opportunistic filter feeder as $\delta^{13}C$ of food source fluctuated from -27.76 to -24.24‰; $\delta^{15}N$ ranged from 1.70 to 5.01‰.

5.4. Summary

This study has treated food sources variations in different landscapes caused by installation of groin for two kinds of *Corbicula bivalves* in a tidal river by using the Iso Source mixing model (Phillips et al.2003) with the carbon and nitrogen stable isotope ratios. According to their results, we could have clarified their food sources and compositions in each growth stage in tidal river with varied landscapes as follows:

1. The density of both of these bivalves showed converse results along the transverse direction. The total densities of *Corbicula japonica* showed lowest values in area with groins, and completely composed by the larger individual. In contrast, *Corbicula leana* showed the highest density in the area without groins, and in each station it is almost composed by M size individuals.

2. The terrain and riparian vegetation probably influence the origin and distribution of SPOMs. SPOMs collected from the area with groins (lower reach) and thalweg area showed enriched values of $\delta^{13}C$ (such as Sts. R, D1, M and U2), which might derive from marine end-member brought by tidal intrusion. SPOMs collected from vegetation invasion area showed lower values of $\delta^{13}C$ indicated that they were derived from vegetation surrounding (such as Sts. D2, U1).

3. Basing on Mixing Mode and IsoSource analysis, it suggested that *Corbicula japonica* was a selective filter feeder, mainly depended on $\delta^{13}C$-deplete TPOM (SPOM from St. D2 and St. U4). In the area with groins, *Corbicula japonica* showed relative lower density than which in area without groins. It indicated that groin took some effect on blocking material transport and resulting in insufficient preferable food source in area with groins. For S size individuals of *Corbicula japonica* (≦7mm) depended on much more TPOM than the larger one. Less S size individuals inhabited in area with groins resulted from insufficient TPOM.

4. Basing on Mixing Mode and IsoSource analysis, *Corbicula leana* might be an opportunistic filter feeder and depend on the SPOM derived from neighbor water column.

Therefore, *Corbicula leana* showed relative higher density in area with groins which was corresponded with abundance of SPOMs in neighbor water area. The $\delta^{15}N$ of S size individuals showed quite lower values than larger individuals, so we could not found the food sources in present study. It indicated that the *Corbicula leana* individuals might shift their food sources in their growth stages. Moreover, it inferred that the area with groins took positive effect on *Corbicula leana* from the aspects of food conditions by trapping a great amount of food sources.

Reference

Hansson, S., Hobbie, J.E., Elmgren, R. and Larsson, U., (1997) The stable nitrogen isotope ratio as a marker of food-web interactions and fish migration, *Ecology*, 78:2249-2257.

Hwang, S.J., Kim, H.S., Shin, J.K., Oh, J.M. and Kong, D.S. (2004) Grazing effects of a freshwater bivalve (*Corbicula leana* Prime) and large zooplankton on phytoplankton communities in two Korean lakes, *Hydrobiologia*, 515: 161-179.

Kasai, A., Horie, H. and Sakamoto, W. (2004) Selection of food sources by *Ruditapes philippinarum* and *Mactra veneriformis* (Bivalva: Mollusca) determined from stable isotope analysis. *Fisheries Science*, 70(1):11-20.

Kasai, A. and Nakata, A., (2005) Utilization of terrestrial organic matter by the bivalve *Corbicula japonica* estimated from stable isotope analysis, *Fishery science*, 71: 151-158.

Kasai, A., Toyohara, H., Nakata, A., Miura, T. and Azuma, N., (2006) Food sources for the bivalve *Corbicula japonica* in the foremost fishing lakes estimated from stable isotope analysis, *Fishery science* 72: 105-114.

Nanbu, R. and Mizuno, T., (2004) Post-settlement growth and mortality of brackish water clam *Corbicula japonica* in the Kiso estuaries, central Japan, *Fisheries Science*, 74 (6):1254-1268.

Phillips, D.L. and Gregg, J.W., (2003) Source partitioning using stable isotopes: coping with too many sources, *Oecologia* 136:261-269.

Pinay, G., Naiman, R. J., (2002) Basic Principles and Ecological Consequences of Changing Water Regimes on Nitrogen Cycling in Fluvial Systems, *Environmental Management*, 30: 481-491

Sakamoto, K., Toyohara, H., (2009a) A comparative study of cellulase and hemicellulose activities of brackish water clam *Corbicula japonica* with those of other marine Veneroida bivalves. *Journal of Experimental Biology*, 212: 2812-2818.

Sakamoto, K., Toyohara, H., (2009b) Putative endogenous xylanase from brackish water clam *Corbicula japonica*. *Comparative Biochemistry and Physiology*, Part B 154: 85-92.

Shin, H.S, Amahashi, N., and Mitamura, O., (2013) Trophic position and growth stages of Caddisfly (*Stenopsyche marmorata* Navas) larvae in the Echi River, Japan, *Limnology*, 14(3): 283-291.

Tsubaki, R. Furuhata, H. and Tsujimoto, T., (2008) Flow structure on groins during flood event and morphological evolution of topography, *Annual Journal of Hydraulic Engineering, JSCE*. 52: 691-696 (In Japanese).

Vanacker, V., Molina, A., Govers, G., Poesen, J., Dercon, G., (2005) River channel response to short-term human-induced change in landscape connectivity in Andean ecosystems, *Geomorphology*,72:340-353.

Yamada, K., Tashiro, T. and Tsujimoto, T., (2014) Effects of sediment replenishment on stream ecosystem below dam and reservoir, their verification with particulate organic matters, aquatic organisms and the stable isotope ratios of carbon and nitrogen, *Limnology in Tokai Region of Japan*, 64: 11-21 (in Japanese).

Chapter 6

CONCLUSION

6.1 Summary

In recent years, groin has been considered as one of the most effective methods to create diverse landscapes and restore natural river ecosystem by changing hydrodynamic regimes with geomorphological process. River estuary is one of the most the most productive fields by providing the material and energy sources from both of the terrestrial and seaward ecosystem. A lot of groins have been installed in the estuary of alluvial river in order to protect and sustain adjacent urban and rural human societies. However, few study concentrated on effects of groins on aquatic organisms in the formed diverse landscapes of the river estuary. This relationship is treated as a key to be clarified since ecosystem conservation is one of the critical issues in river management.

The primary goal of this study is to investigate responses of distribution of dominant benthic organism and their food sources variations to the series of groins installation with (a)summarizing the geomorphology evolution in Kiso river estuary and finding out the major physical environment factors affecting target benthic organisms (*Corbicula bivalves*) base on literature review, (b) examining the influences of spatial shift of environment variables caused by groins construction on *Corbicula* bivalves' habitat in sub tidal zone, (c) clarifying food sources variation in different landscapes caused by groin construction.

6.1.1 Landscapes and habitat environment for Corbicula bivalves

This part reviewed the studies regarding geomorphology evolution and the responses of physical environment conditions to installation of a series of groins in the research area of Kiso estuary. And, critical environmental factors that affected *Corbicula* bivalves' inhabitation are also intended to be identified by reviewing previous works. These pervious works were reviewed in order to set the specific target field, clarify the critical environmental factors for *Corbicula* bivalves' inhabitation and the research method.

30 groins in Kiso estuary and divided into two types were constructed along the right bank of the river, from 12 to 25 river kilometers of river mouth. The geomorphological evolution was not homogeneously along the longitudinal direction. The landscapes characteristic by (a) wide area of water from 15Rkm to 17Rkm, (b) the sedimentary developing from 17Rkm to 19Rkm, (c) the developed terrestrial landscapes from 19Rkm to 23Rkm. To generalize the effect of installation of a series of groins on *Corbicula* bivalves, this study proposed the environment variations in longitudinal and transverse directions effect on *Corbicula* bivalves. The previous study indicated *Corbicula Japonica* showed higher density in sub tidal zone compared to the in inter tidal zone, thus current study, the effect of environmental factors on inhabitation of *Corbicula japonica* in sub tidal zone were discussed.

The water conditions (water depth), salinity conditions, substrate conditions (sediment size, BPOM) and food conditions are strongly influenced *Corbicula* bivalves' inhabitation. Since the environment variables were not independent but combined together to influence *Corbicula* bivalves, it was recognized that the effects of environmental factors on their distributions were needed to be quantitatively described.

6.12 Habitat and food sources of Corbicula bivalves with series of groins

This part intended to examine influences of spatial shift of environment variables caused by a series of groins construction on *Corbicula* bivalves' habitat in sub tidal zone of the Kiso river with a series of groins focusing on three kinds of environment factors- water environmental factors (salinity, Chl. a, water depth and their variation), substrate condition (silt rate, D50, Cu and Cc), diet condition (SPOM and BFPOM).

Two-way ANOVA was utilized to evaluate the main effects of the longitudinal direction and transverse direction in all environmental variables biomass and density of *Corbicula japonica*. Salinity exhibited significant differences along the longitudinal direction. However, there was non-significant difference along the transverse direction. Water depth was significantly affected by longitudinal and transverse directions. Water depth was shallower in upper locations and without groin area. Substrate environment variables and diet conditions were not significantly affected by the effects of longitudinal and transverse directions. Principal component analysis (PCA) was applied to indicate the approximate changes of substrate environment variables and diet conditions. The variations of substrate and diet conditions in the area with groins were smaller than those in the area without groins.

Biomass and density of *Corbicula japonica* were significantly affected by longitudinal direction, but not significantly affected by transverse direction with higher biomass and density in 12 R km section. The biomass and density of *Corbicula leana* did not show significant differences neither along longitudinal nor transverse directions.

In order to describe the biomass and density by environmental factors, the multiple regression analysis has been performed. The biomass of *Corbicula japonica* could be described by standardized coefficients of the mean of salinity (1.03) and water depth (-0.14). The density of

Corbicula japonica could be described by standardized coefficients of the mean of salinity (0.62) and Cu (0.43). The biomass of *Corbicula leana* could be described by standardized coefficients of the Cc (0.64) and mean of salinity (0.45). The density of *Corbicula leana* could not be described by regression equation.

6.13Food sources in different landscapes for Corbicula bivalves

This part intended to examine impact of different landscapes (with groin, main stream area and without groin area) on *Corbicula* bivalves' food sources variation caused by groins construction in sub tidal zone basing on stable isotope analysis, with potential food sources (SPOMs) collected from 9 stations in upper and lower estuary. SPOMs have been categorized with stable isotope ratios by Cluster analysis in order to understand their origin. The sampled SPOMs were categorized into 4 groups.

Stable isotope signatures of *Corbicula* bivalves were examined in three different landscapes area and three different life stages. In the same area, all of life stages of *Corbicula japonica* showed relative lower $\delta^{13}C$ and higher $\delta^{15}N$ values than *Corbicula leana*. Stable isotope signatures for L and M size of both two bivalves showed the highest values in with groin area. The S size of both of two bivalves showed relatively lower $\delta^{15}N$ values than the larger individuals, which implied that they might take relatively depleted-$\delta^{15}N$ SPOM as the main diet.

"Isosource" mixing model with $\delta^{13}C$ and $\delta^{15}N$ signatures was utilized to qualitatively describe the potential food sources. *Corbicula japonica* showed greatly utilization of $\delta^{13}C$-depleted SPOM. It indicated TPOM was the mainly food composition. *Corbicula leana* greatly changed their food sources among different landscapes: in area with groin, neighbor SPOM was the main food source; while in area without groin and thalweg, the percentage of $\delta^{13}C$-depleted SPOM increased.

6.2 Implications

This study has conduct research on *Corbicula* bivalves' habitat food sources impacts following a series of groins installation. Based on discussing the effect of environment variables variations *Corbicula* bivalves' habitat, and the variation of the food sources in different landscapes, the finds and concluding remarks are mentioned as follow:

From the effect of installation of groin on environmental variables, distribution of *Corbicula* bivalves

- In transverse direction, salinity exhibited relative higher values in the area with groin than without groin, water depth showed significantly higher values in with groin area. It indicated that a series of groins took great influence in changing the topography of riverbed and caused a larger deep water area, but less influence in changing salinity.
- Diverse sediment size occurred in the upper cross-section (12Rkm) and lower cross-section (20Rkm) cross-section, and homogeneous sediment size characteristic in the middle section of the series of groins segment (17Rkm cross-section). Substrate environment variables showed homogenous characteristics in the area with groins compare to without groin.
- Compared with the area with groins and without groins, biomass and density of *Corbicula japonica* did not show significant different due to similar levels of salinity and less important factor water depth (standardized coefficients:-0.14). Along the longitudinal direction, the increasing trend of the biomass and density are attributed to significant increased salinity level.

- The biomass of *Corbicula leana* did not show significantly different in transverse and longitudinal directions due to the irregular changes of Cc and less effect of salinity. Fine sediment plays the most important role in supporting higher biomass of *Corbicula leana*.

From the effect of different landscapes caused by installation of groins on food variation

- Groin terrain and riparian vegetation probably influence the origin and distribution of SPOMs. SPOMs collected from with groin area (lower reach) and thalweg area showed enriched values of $\delta^{13}C$, which might derive from more marine end-member. SPOMs collected from vegetation invasion area showed lower values of $\delta^{13}C$ indicated that they were mainly derived from vegetation surrounding.
- The *Corbicula japonica* was selective filter feeder, mainly depended on TPOM. In with groin area, *Corbicula japonica* showed relative lower density in the area with groins than without groins. It indicated that groins took some effect on blocking material transport and resulting in insufficient preferable food sources in area with groins. For S size individuals of *Corbicula japonica* ($\leqq$7mm) depended on much more TPOM than the larger one. Less S size individuals inhabit in area with groins might result from insufficient TPOM.
- The *Corbicula leana* might be opportunistic filter feeder and depend on the SPOM derived from neighbor water column. Groins have some effect on increasing the density of opportunistic filter feeder since great amount of food sources are trapped in the area with groins. Therefore, *Corbicula leana* showed relative higher density in the area with groins which was corresponded with abundance of SPOMs in neighbor water area. The $\delta^{15}N$ of S size individuals showed quite lower values than larger individuals, so we

could not found the food sources in present study. It indicated that the *Corbicula leana* individuals might shift their food sources depending on different growth stages.

Comprehensively, the implication of this study and future work suggested as follow:

A series of groins installation obviously changed the geomorphology in Kiso estuary, and caused significant deepen water area behind groin. Salinity showed relative higher values in the area with groins probably because that in the stagnant area the salinity was affected by relatively high tide, the water might be hardly exchanged with that in thalweg zone and the salinity concentration could be conserved. Groins installation also influenced the origin and distribution of food sources (SPOMs) to some extent by promoting a bit more marine particulate organic matter assembled in the area with groins.

The distributions (biomass and density) of these two species did not show significantly different in area with and without groins. The reasons are that distributions of them are mainly controlled by salinity and diverse of sediment, while both of these two environmental factors do not show obviously differences between the area with groins and without groins. However, the extended brackish water zone along the longitudinal direction in area with groins was found by numerical simulation analysis (Shionoya, 2006), it is suggested that the area with groins probably sustain more *Corbicula* individuals than the area without groins.

The installation of groins has less effect on the distribution of *Corbicula* bivalves. However, it has been illustrated that the brackish water zone was extended due to groins installation (Shionoya, 2006). It indicated that the area with groins probably sustain more *Corbicula* individuals than the area without groins.

Corbicula japonica is identified as selective filter feeder, *Corbicula leana* is examined as opportunistic filter feeder. Therefore, groins have some effect on increasing the density of opportunistic filter feeder since great amount of food sources are trapped in the area with groins.

On the hand, the density of selective filter feeder is limited due to the preferable food source (TPOM) is blocked by the groin to some extent.

The cellulase activities endogenous cellulase genes have been identified in the body of *Corbicula japonica*, (Sakamoto et al., 2009b). It is indicated that *Corbicula japonica* have the capacity of digestion of terrestrial organic matters. These findings can support the present research result.

It has been clarified that *Corbicula leana* was extending throughout of Japan, with more tolerant of water pollution than other species of this genus (Lee et al., 1997). It might threat the *Corbicula japonica* inhabitation. However, in the present study, due to the different requirement for habitat environment and food sources, there no competition between two of the species in the present field.

The previous studies indicated that groins took an important role in improving biodiversity according to creating diverse landscapes in coasts or upstream of rivers. In current study, the differences biomass and density for these two species between in area with groins and without groins is not significant. However, the positive effect of a series of groins on fish inhabitation is expected, since some of them were proved to preferring diverse flow velocities or the haven area in deep scour holes in previous research.

In the present study, I targeted on comparing the differences of inhabitation of *Corbicula bivalves* in scour hole in the area with groins and without groin in subtidal zone. However, according to distance from groin, the physical environment varied, so as to affect the macro faunal assemblages (Walker et al. 2008). Therefore, it is necessary to check the effect of groins on distribution of *Corbicula* bivalves in other locations in the embayment area.

Due to the lack of experience, some study issues have not been clarified yet. For example, in chapter 3, due to different landscapes in transverse and longitudinal directions, the study aims were determined to discuss the effect of groins on dominant benthic organism in these two directions. However, as the result, we just concerned and discussed in transverse direction. In lower reach of area with groins, the density and biomass of these two bivalves showed relative higher values than those in upper reach owing to the relative higher salinity level and diverse sediment size. However, it could not be judge that the groins in lower reach are superior to those in upper reach in sustaining the suitable habitat for these two bivalves, because the this phenomenon is not only caused by the different structures and materials of the groins but also the locations - higher salinity level in low estuary. Therefore, the discrepancy of ecological function of groins in upper reach (permeable groins) and lower reach (impermeable groins) needs to be assessed respectively in the future.