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Ecosystem and Fishery of Manila Clam (*Ruditapes philippinarum*) in Ise-Bay Related to Eco-Compatible Management of Its River Basin Complex

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Abstract

Ise bay, Japan, is located at the river mouth of 10 class-A rivers, and its environment is closely related to management of their river basin complex (RBC). We developed a model to describe the ecosystem of RBC by developing three tool boxes: TB1 to describe the water/material flux network, TB2 to describe ecosystem mechanism in various categories of landscapes, and TB3 to standardize ecosystem services received at local sites and integrate them throughout RBC. Ecosystem has a function to change the fluxes, which is evaluated by TB2, and such flux change can be fed back to the flux networks in TB1. The outputs of the fluxes from the RBC are inputs for currents of water with various qualities to the bay, which can be computed by bay-dynamics modeling. Then it provides various fluxes from the bay interior to landscapes located along coastal zone, and it supports ecosystem there. Fishery is a kind of ecosystem service there. We focused on bivalve, Manila clam (*Ruditapes philippinarum*) because it uses various landscapes in a bay through its life cycle and it provides fishery activity as ecosystem service. We have developed TB1 and TB2 also in bay area successfully. Then, we evaluate the transition of quality of environments of RBC including Ise bay from the past to the present by using TB1-TB3 for river basin and bay area. Furthermore, we forecast the future situation and then we discuss how we can improve it through various combinations of measures and policies in the RBC as well as in the bay.

Keywords: Eco-compatible management; River basin complex; Ecosystem; Fishery activity; Manila clam (*Ruditapes hilippinarum*)

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1. Introduction

Many metropolises are located at the river mouths or in the floodplains, and they are supported by natural resources and human activities in basin of the rivers. If the metropolis is too highly populated with productivities, it is sometimes a stress for the basin, and on the other hand the activities in the basin becomes heavy load for the bay which is the outlet of the rivers to collect water and materials around the basin. It causes damage in water quality, ecosystem and human activities such as fishery, recreation, amenity *etc*., and reversely it becomes a stress for the metropolitan who are now aware of environment around them. After 80's the efforts to restore the bay started with regulation of waste water from industries and equipment of waste water treatment facilities with sewage system. It was often termed "point-source" measures against water pollution. However, environmental load is scattered around the basin and measures against such so-called "non-point" sources (distributing sources) have not been well proceeded.

When the Council for Science and Technology Policy was founded in the Cabinet Office of the Government in 2001, "environment" was chosen as one of the important topics in science and technology, and "eco-compatible river basin complex and urban restoration" was chosen as one of the initiative research projects among multiple ministries. The main interests of the initiative research projects were to improve the accuracy of "unit load" for characteristic land use to estimate the input of materials from the basin to the bay and to estimate the improvement of water quality from the view point of environmental criteria. It was considered that the decrease of the unit load is contributed by eco-compatible policy menus and that the improvement of water quality in the bay has advantageous also in improvement of ecosystem, fishery, recreation and amenity. Furthermore, it pointed out how the eco-compatible management menus contribute the improvement of habitats of some organisms [1].

Responding to the recruitment of research program by special coordination fund for promoting science and technology for sustainable national land management, we conducted the project "Research and development in assessment and restoration for eco-compatible management of river basin complex around Ise bay" (2006-2011) supported by MEXT (the Ministry of education, culture, sports, science and technology, Japan). We focused on coastal ecosystem in the bay and related fishery activity as well as the water quality in the bay. Then, we focused on various landscapes in the river basin complex and eco-compatible management of landscapes and water-material flux network connecting them, which may result the improvement of ecosystem services on various landscapes as well as the suppression of environmental load reaching the bay. Landscape is a concept of a set of natural characteristics and human activity, and it forms an ecosystem which brings various functions to suppress the threats against sustainability through the "ecosystem service". As mentioned above, the river basin is recognized as an assembly of water/material flux networks and various landscapes scattering there connected each other by flux networks. We have prepared a tool box to describe water/material flux networks (TB1) and one to describe categorized landscapes as an interrelating system among physical basement, biological aspect and material cycle, which is just an ecosystem (TB2). Not only in a river basin but also in the bay area, water and materials are transported and changed with hydrodynamics in a bay (TB1) and we expect categorized landscapes along the coastal zone to develop TB2 [2].

Corresponding to the increase of population and economic activities, landscape has been degenerated with increase of artificial facilities and additional flux networks have been connected to the natural ones. Multiple river basins have been thus connected and the outlets of these basins have affected the bay environment and human activities there. We have defined such a unified area as "river basin complex". Particularly in the Ise bay area, fishery of Manila clam (*Ruditapes philippinarum*) has been active but the production (catch) has been decreased. In addition, because Manila clam uses various specific spaces in a bay and its coastal zone in its life cycle, its study is expected to demonstrate an interacted discussion on water quality, ecosystem and fishery (human activity).

In this paper, the authors explain how we recognize the river basin complex, how the eco-compatible management brings the ecosystem services and improves the environmental load to the bay, and how the target of bay restoration program is designed, based on the result of the 5 years project "Research and development in assessment and restoration for eco-compatible management of river basin complex around Ise bay"

2. Ecosystem and River Basin Complex

In the previous research, eco-compatible river basin management intended to suppress the environmental load from non-point source to the bay and only the improvement of habitats for specific species was discussed for inland area with decrease in unit of environmental load. They never discussed landscape function. Furthermore in the bay area, they assumed a priori that the improvement in water quality results the restoration of eco-system and fishery and never discussed ecosystem dynamics apparently.

In our study, we focused on landscapes scattering in the river basin complex which cause the changes in fluxes and bring ecosystem service, and first of all we clarified the concept of structure and functions of ecosystem and ecosystem service.

2.1. Structure and functions of ecosystem

We recognize that ecosystem is an interrelating system among physical basement, biological aspects and material cycle (particularly in biophilic elements) as shown in Fig. 1. The physical basement subjected to the flow, sediment transport and fluvial process provides habitats of various species of organisms and peculiar spaces appropriate for peculiar elementary processes in material cycles. Biological aspects are behaviors of individual growth, population dynamics and constitutions of various species, and they are supported by habitats and biophilic elements cycles (assimilation, deposition, *etc*.). Such an interrelating system is considered as structure of ecosystem, and interactions among factors must be recognized as ecosystem functions. If the water/material fluxes pass through this system, it changes the fluxes and brings various functions which are fundamentally indicated by the arrows shown in Fig.1 [3].

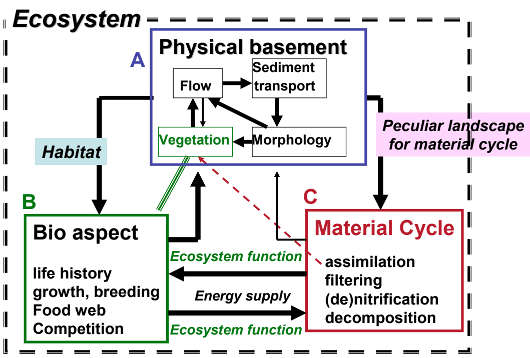

Fig. 1. Structure and functions of ecosystem

Among the ecosystem functions, we expect the mitigation of the threats against the "sustainability", and we recognize it as "ecosystem service". The concept of ecosystem service was originally introduced for estimating values of ecosystem in currency base [4]. On the other hand, we recognize ecosystem service as values to mitigate the threats against the sustainability, which are depletion of resources (particularly fossil fuels), global warming (climate change) and biodiversity loss. Figure 2 shows the relations between the classification of ecosystem service in UN millennium assessment [5] and the sustainability index. For example, the adjustment functions and production services can be related to decrease in fossil fuel consumption and green house gas emission, while habitat provision can be related to conservation of biodiversity. Cultural aspects might promote eco-compatible management and/or policies with citizen consensus.

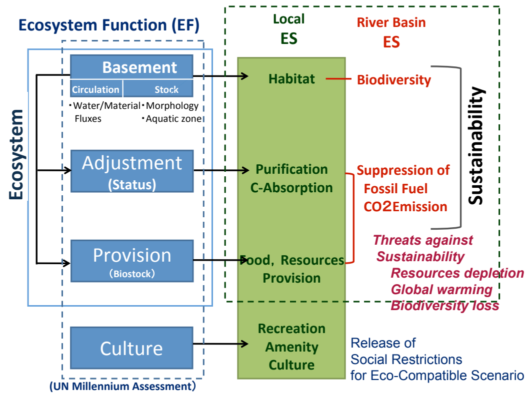

Fig. 2. Ecosystem service

2.2. River Basin Complex

River basin is a unit of water cycle and surrounded by a divide. With in a river basin, water is concentrated into river system, and not only water but also sediment is transported and forming fluvial morphology. With water and sediment, other materials are also transported within a river basin. In particular, biophilic elements are changing the forms into inorganic to organic and sometimes in biomass, and then it is quite related to ecosystem. In this sense, a river basin is recognized as an assembly of water/material flux networks. On the flux network, there are several landscapes which are spaces characterized by natural features with human activities as shown in Fig.3(a). Hence, the landscape is often categorized by geographical features and land-use. Each landscape has the structure of ecosystem explained in *2.1*, and it is connected to the others by water/material flux networks. When the fluxes pass through a landscape, it causes the change of fluxes and brings some ecosystem service there as explained in *2.1*. The ecosystem service has supported the human activity there, but in order to support more human activity with economic efficiency, artificial flux networks (such as irrigation canals, water supply and sewage system, *etc.*) and facilities have been added to this system, and then multiple river basins are connected together closely. Such a close combination is defined as a "river basin complex" (see Fig.3(b)). And, multiple river basins are neighboring along a bay and form a metropolis. The flux outlets from those basins are the same bay, and then, river basin complex, bay and metropolis are the same destiny. Ise bay river basin complex is one example (see Fig.4).

We now recognize the inland behavior affects the bay environment, where the water/material flux is hydrodynamic behavior in the bay driven by inflow from inland and weather condition such as wind and tide with the condition at the boundary with the ocean. And along the coastal zone of the bay, we recognize various landscapes where the ecosystem related to the human activity. This system is schematically illustrated in Fig.4(a), where various landscapes cause the change of the flux and bring various ecosystem services. Figure 4(b) shows a satellite photo of the Ise bay river basin complex to demonstrate a connected river basin complex, metropolis and a bay surrounded by several basins.

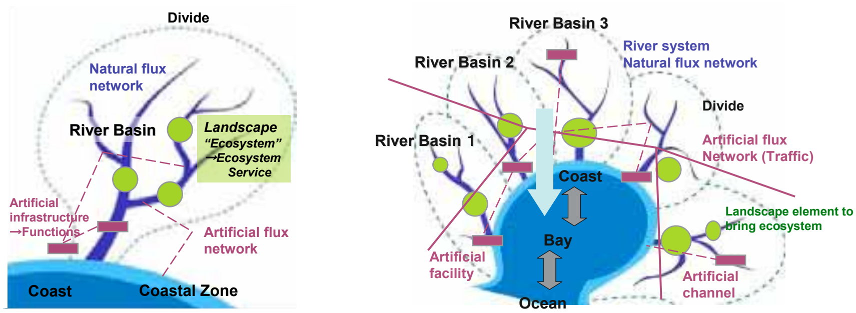

Fig. 3. (a)River basin; (b)River basin complex

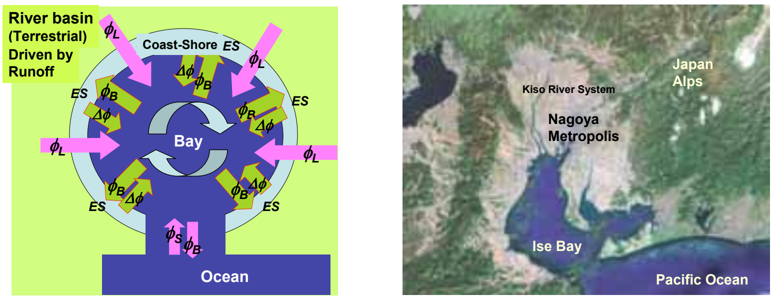

Fig. 4. (a)Flux networks in a bay and landscapes along its coast; (b)Satellite photo of Ise bay river basin complex

3. Description of Eco-Compatibility of River Basin Complex

In order to describe the river basin complex, it is necessary to develop the tool boxes to describe water/material flux network TB1 and to describe landscape functions (change of flux and ecosystem service) based on the ecosystem mechanism (TB2) both for the inland and for the bay area.

TB1 in the inland has been established based on a runoff model, which has connected with artificial networks and facilities, and equipped the interfaces to TB2. In calculation, we have employed sub-basin division which has a hillside and a channel for each sub-basin. The parameters involved in a hillside and a channel model are determined by area-weight base procedure depending on the data base of geography and land-use. The precipitation can be input by interpolation from the data from observatories. Landscapes have different spatial scales but their inputs and outputs are exchanged through nodal points of sub-basins. The present model can treat COD, TN, TP and SS as well as water (discharge), and their time-space distributions are described. If we focus on some landscape, the inflow fluxes are known and we evaluate the change of fluxes and peculiar ecosystem service there by using TB2.

The typical categorized landscapes in our research project are as follows: (1) natural forest and artificial one, (2) gravel bed rivers affected by dams, (3) river segment with riffles and pools, (4) sandy bed with regulated discharge, (4) combined agricultural lands with rice pad, (5) channel network between rivers and rice pads, (6) brackish pond in floodplain. And, TB2 has been developed for those categorized landscapes. Depending on the characteristics of categorized landscape, we can postulate the degeneration in these decades and expected restoration and/or rehabilitation menus. TB2 can evaluate the change of fluxes and ecosystem services with or without human activities or restoration menus.

TB1 with TB2 of inland can give the output fluxes into the bay, and they become the boundary condition for TB1 in the bay area, which is hydrodynamic modeling driven by tidal and wind action. Then we discuss landscape along the coastal zone and thus we have developed TB2 for the bay area.

TB1 and TB2 for the inland and for the bay area are combined, and then the accumulated ecosystem service in various types must be discussed for the assessment of several scenarios of eco-compatible management (TB3).

4. Modeling of Hydrodynamic Behavior of Bay and Life Cycle of Manila Clam

TB1 for the bay area is 3D hydrodynamic modeling associated with water quality and primary production, and it provides the time-space distribution of various characteristic quantities such as flow velocity, salinity, temperature, dissolved oxygen (DO), chemical oxygen demand (COD), total-nitrogen (TN), total phosphorus (TP), chlorophyll-a (Chl-a), and so on. In the present study, numerical calculation is executed in the scheme with horizontal mesh of 2km and with vertical mesh of 10m, and according to tide, wind, air temperature, the discharge of major rivers with various materials and the boundary condition with the ocean, the time-space distribution of velocity vector, temperature, dissolved oxygen, several nutrient indices are calculated. The calculated results for the present situation by using the monitored inflow fluxes from the inland, weather condition, tide and the boundary condition at the border with the ocean was certificated the monitored data in the bay.

In the bay area, we have postulated several landscapes along its coast. Particular in the Ise bay area, we have focused on a typical species of bivalvia, Manila clam, *Ruditapes philippinarum*, which is a symbolic species for fishery in this area. In addition, this species uses various spaces in the bay area in its life cycle. Thus, the Manila clam becomes a key when we discuss ecosystem related to human activity.

The main habitat of the Manila clam is a tidal flat as a categorized landscape. Tidal flat landscapes are located along shore of the Ise bay as shown in Fig.5(a). The clams spawn in one tidal flat, and their larvae drift to disperse in the bay by hydrodynamics to grow. Then, juveniles deposit on some of tidal flats. In other words, they exchange individuals among several tidal flats as shown in Fig.5(b). After stable settlement of juvenile on a tidal flat, it grows by uptaking particulate organic matters. Then, after they grow matured they spawn and/or become fishery resources. Based on such history of life (Fig.6(a)), tidal flats distributed inside a bay contribute a meta-population of *Ruditapes philippinarum*. It is necessary to describe the drifting behavior of larvae (from where to where) subjected to the hydrodynamics, stability for landing of juveniles which is subjected to the flow intensity and stability of substratum, and the growing process to be matured. They are parts of TB2 for tidal flat landscape with clam ecosystem and its boundary conditions given by TB1. While, the increasing of biomass is identified with accumulation of nutrients inside of clam, and it implies the clam fishery takes a role of water purification. The relation between TB1 and TB2 in the bay is illustrated in Fig.6(b).

Figure 7 summarizes the relations between life history of Manila clam (*Ruditapes philippinarum*) and environmental conditions, and it suggests the restoration strategies, some of which are related to the basin management in inland and the other may be done directly on the coastal side.

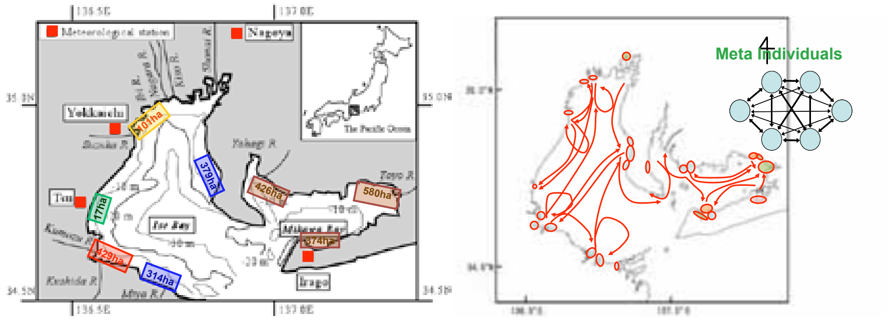

Fig. 5(a). Tidal flat landscapes along the coastal zone of the Ise bay; (b)Exchange of individuals to form meta-individuals

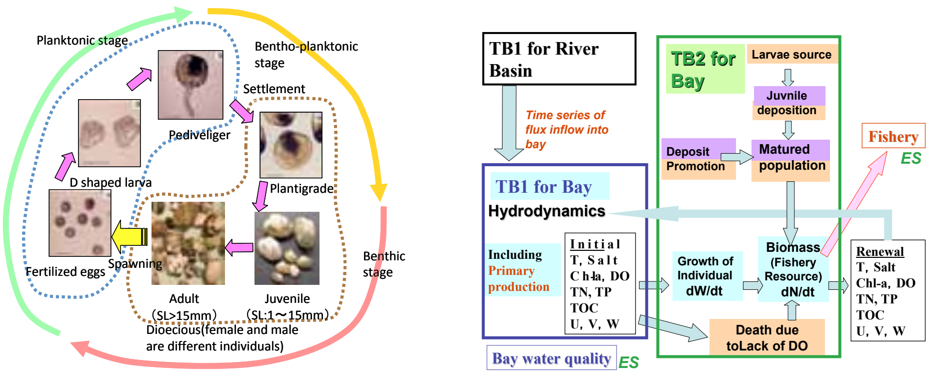

Fig. 6(a). Life history of Ruditapes philippinarum; (b) Relation between TB1 and TB2 in the bay area.

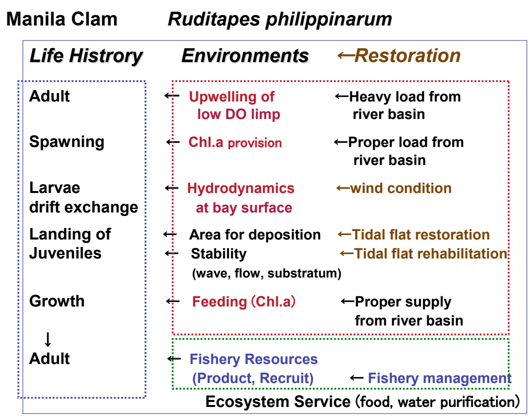

Fig. 7. Relations among life history of Manila clam, environmental condition and restoration strategy

NIRIA and NRIFE (National Research Institute of Aquaculture and Fisheries Engineering) conducted larvae drift simulation by using hydrodynamic model (see Fig.8)[9], and they obtained the exchange rate of larvae among various tidal flats along the Ise bay. From the field observations, it was known that the Manila clams spawn twice a year, and larvae drift to exchange habitats. After growing of larvae, they settle on some of tidal flats. Then, we estimated the number of clams to start to grow proportional to the area and stability condition of each tidal flat. The latter was determined depending on the wave-induced current conditions and substratum size, and we obtained the method how to estimate the ratio of proceeding to the growing process. The stability condition of the substratum is sometimes influenced by Nori-culture nets. After settlement on tidal flat successfully, it grows depending on the feeding condition (mainly on Chlorophyll-a) but it is often damaged by storm disturbance and serious deficit of dissolved oxygen. Considering the events to death of the clam due to deficit of DO, we set the death rate depending on local and averaged values of DO near the bottom. On the other hand, NIES (National Institute for Environmental Studies) prepared a model to describe the growth of individuals and simultaneously accumulation of filtered particulate organic matter based on the study by Hiwatari *et al.* [10].

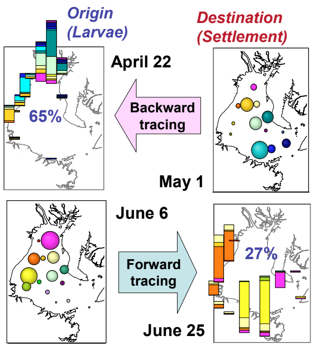

Fig. 8. Origin destination survey of larvae exchanging by drift

5. Issues of River Basin Complex and Future Scenario for Eco-Compatible Management

We have developed the model to describe the river basin as water/flux network with the functions of landscapes, the output fluxes to the bay, time-space distributions of fluxes with hydrodynamics in the bay and the status of the bay expressed by water quality, ecosystem and fishery activity. Thus, it is possible to recognize the present status of the basin complex. First of all, mesh data are prepared for geographical properties, land-use, population and so on. Artificial facilities and flux networks such as dams, intakes, water supply, irrigation system, sewage system with waste water treatment facilities and so on and their operations rules are listed. Time series of spatial distribution of precipitation is prepared. They are updated for different time. Then, the time-space distributions of water/material flux are calculated, and we can evaluate ecosystem service at the focused landscapes. We can recognize the role of the landscapes on change in fluxes and ecosystem service at local sites. Sometimes, the integrated values for the whole basin are also analyzed.

Next, the bay circulation is calculated with the boundary conditions of inflow fluxes calculated for the basin and the others such as wind, tide and ocean behaviors. Furthermore, the clam biomass is calculated for several tidal flats by life history modeling of Manila clam (*Ruditapes philippinarum*). (1) Spawning number related to Chl-a, (2) exchange rate of larvae depending on the surface flow behavior, (3) settlement and addition to growing stage from juvenile to adult depending on area of the tidal flat and stability of the substratum there, (4) growth and death process under low DO behavior, and (5) separation between fishery and recruiting adults. Then we discuss on the water quality of the bay compared with environmental criteria officially indicated and ecosystem service such as the fishery product (catch).

5.1. Present Status of Ise River Basin Complex

First of all, we have conducted the calculation of the basin status at present. The mesh data for 2000 was employed, while the precipitation data for 1999 was employed which was regarded as a hydrologically standard year. The calculated fluxes of water and materials (COD, TN, TP, SS) were compared with the monitoring data for partial certification of the present calculation procedure. And, some ecosystem services were computed by the proposed TB2 for focused landscapes. Furthermore, the output fluxes were imposed to the analysis in the bay. We recognized that TB1 for the bay reproduced the monitored data for bay environments such as flow velocity, salinity, temperature, dissolved oxygen (DO), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), chlorophyll-a (Chl-a), and so on. Fig.9 shows the calculated results with the monitored data as an example for DO to demonstrate how the present TB1 can reproduce the monitored data. Furthermore, Fig.10 shows the change of fishery product of Manila clam by using TB2 where the life history is taken into account, where the parameters in the model were tested trial and error.

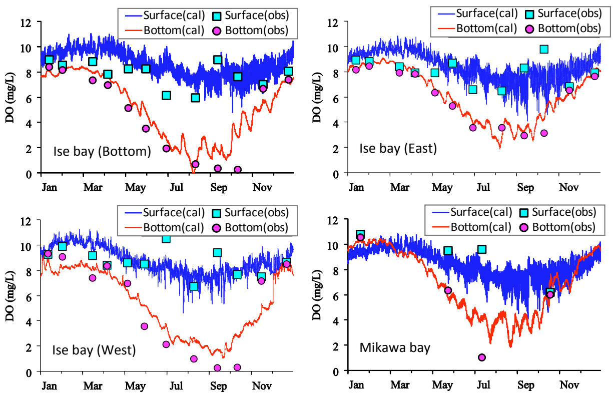

Fig.9. Calculated results of DO with the monitored data

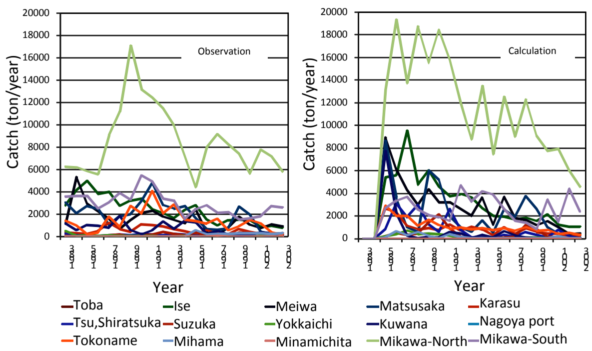

Fig.10. Change of fishery product of Manila clam

Then, we calculated the previous status to recognize the transition of environments. Instead of the calculation for long period, we computed one year 1960 to represent the past, where we employed the mesh data for 1960 but the precipitation condition was set as 1999 in order to recognize the human activities on the river basin to avoid the weather. Furthermore, we conducted the calculation of the future status with no additional policy scenarios, where the future prediction data base was employed for 2030.

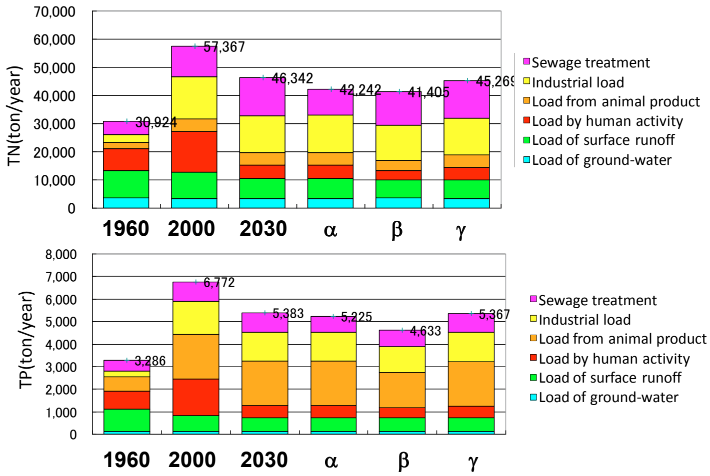

Fig.11. Total output flux of TN and TP per year

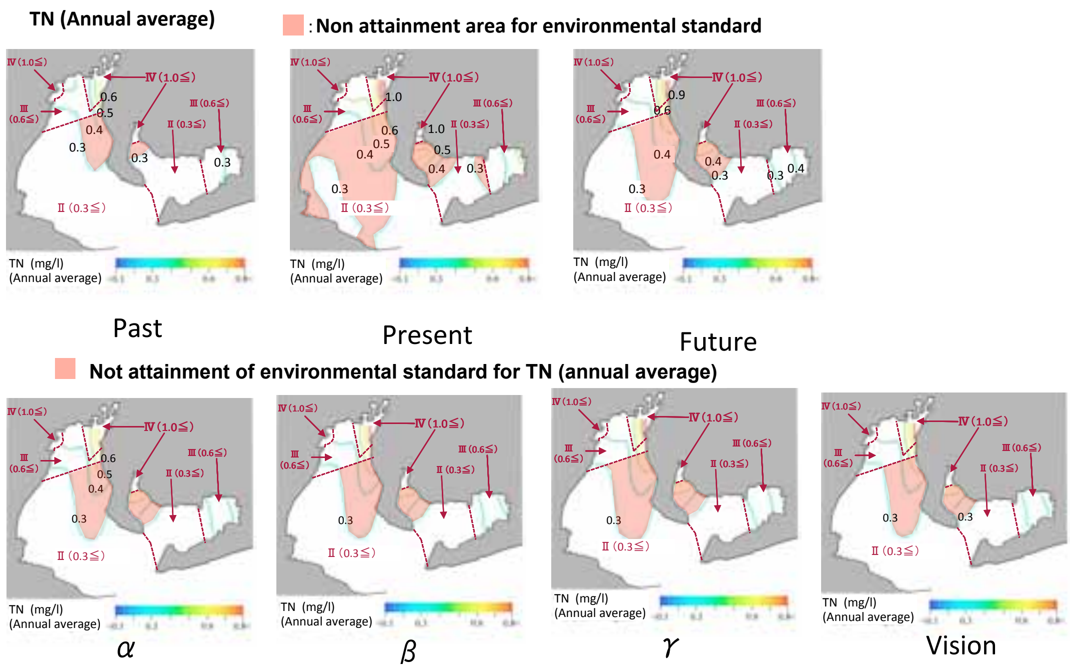

Fig.12. TN contour and how the unaccomplished area from the official criterion changes

By comparing those results, we can discuss the transition of river basin environment from the past to the present and how it would change in future without any scenarios. The calculated results are shown in Fig.11, where total output flux of TN and TP per year are compared each other. In the figure, the results under some scenarios are also shown and they will be referred in the next section. We recognize the environmental load increased from the past to the present, and in the future it will decrease even without any scenarios. We also recognize the change of ecosystem service as the output of TB2. Corresponding to the change of the load from the inland, the bay environments change. From the view point of water quality, Fig.12 shows the TN contour and how the unaccomplished area of the official criterion changes, for example. As for COD, the coastal zone may be gradually improved but the central part of the bay cannot reach the criterion.

5.2. Scnario for Eco-Compatible Management

In this section, management scenarios are discussed. Here a scenario is considered as a combination of several policy menus, and we categorize policy menus in the following three groups: (α) infrastructure type such as more construction of sewage system, higher performance treatment system, improvement of composed sewage system, direct water purification in rivers and so on; (β) changes in ways of agriculture, cattle breeding, so on, changes in city life style and so on; (γ) eco-compatible menus such as close-to-nature works, environmental flow release, nature restoration and so on.

In order to investigate the characteristics of the categories of policy menus, we tested the effects of the scenarios α, β, and γ where the policy menus belonging to the each category are employed as much as possible. The efficiencies are checked in terms of the output fluxes from the basin inland to the bay, and the results are shown in Fig.13. Comparing the results for several scenarios, we recommend one scenario under the vision of eco-compatible management of river basin complex, where γ type policies are to be done, α is partially employed for urbanized area (where the eco-compatible menus cannot be employed) and β is partially employed in the mixed area of agriculture and cattle breeding.

Under the vision scenario, water quality is somewhat improved but it is still difficult to accomplish the official environmental criterion as shown in Fig.13. When we focus on product of Manila clam, we have to consider the death rate affected by low DO, then a model to subject it is proposed where the death rate is correlated not only the local values but also the total volume of low DO. Figure 14 shows the differences in the clam products for different scenarios.

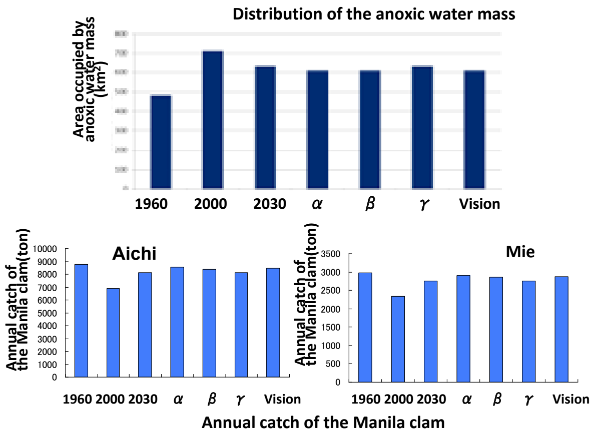

Fig.13. Differences in the clam products for different scenarios

6. Conclusion

In this study, we explained the assessment framework for the sustainability of river basin complex to compare several scenarios of policy menus. The framework is based on the clearly defined concepts of water/flux network, scattering landscapes, ecosystem functions and ecosystem services. Then, the methodology from the view point of bay restoration is developed and tested. We expect the basin management to receive more ecosystem service to suppress the threats against the sustainability, and bay restoration includes rehabilitation of fishery as well as improvement of water quality. This assessment framework is composed of many components (modules) with possibilities of update for refinement in their modeling.

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