Assessment of environmental restoration plans for a small-scale beach by simulation-based habitat evaluation

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***Abstract*— In order to assess the effect of environmental restoration plans for a small scale beach called Heda-Mihama, simulation-based habitat evaluation approach is employed. A three-dimensional hydrodynamic model is developed by using the measured topography to reproduce the characteristics of currents around Heda-Mihama. A sediment transport model is also developed to predict the distribution and change of sediment size at the target site. For the assessment of the ecological value of the site, HEP (Habitat Evaluation Procedure) is employed, in which one of the typical species of bivalves is chosen as a target species. Water depth, sediment size, bottom friction velocity are chosen as the environmental factors for the target species. The suitable indices (SI) for each environmental factors are calculated by using the results of hydrodynamic and sediment transport simulations. By using the developed scheme, habitat values are evaluated for the proposed restoration plans and compared to the current values. It is predicted that the removal of the piers will significantly increase the habitat value of the target site. It is because the water current is significantly increased which make the sediment size larger as well as promote the water exchange at the site.**

I. Introduction

Heda Bay is a small bay located on western coast of Izu peninsula, Japan and surrounded by steep hills and the sand bank called Mihama(Fig. 1). In 1950's and 1960's, Mihama had been famous for the richness in shell fauna, and, for example, nearly 400 species including rare ones were collected. In recent years, however, the impoverishment of ecosystem function had become considerable, which led us to project the investigation on the origin and restoration.

The project team carried out field survey in which water current, water quality, benthic quality, benthos and sessile organisms are examined[1]. In the sea area in the vicinity of Mihama, measured dissolved oxygen level (DO) of the bottom water, oxidation-reduction potential (ORP), benthos fauna suggested the accumulation of organic substances, which causes degradation of benthic environment, e.g. low DO concentration. On the contrary, inter-tidal sessile organisms on a sea wall and a bank indicated the sound state of surface water. These facts induce the possible explanation that the impoverishment of Mihama is derived not from surface water but from the benthic environment. The measured water current at the site is quite small, which indicates the water exchange is very weak. It should be one of the main causes of unfavorable benthic environment. Thus environmental restoration plans for Mihama is proposed in which the pears blocking the water current be removed.

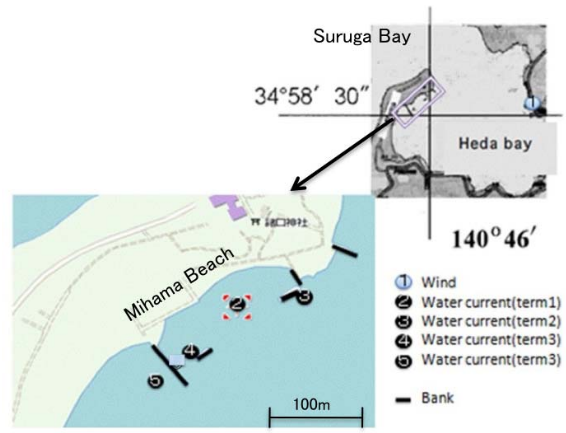

Fig. 1. Target site.

In order to assess the effect of proposed environmental restoration plans, simulation-based habitat evaluation approach is employed. Additional field measurement was carried out for the purpose of collecting the data necessary to develop and validate the simulation models. A three-dimensional hydrodynamic model is developed by using the measured topography to reproduce the characteristics of currents around Heda-Mihama. A sediment transport model is also developed to predict the distribution and change of sediment size at the target site. The trend of topographical change due to the sediment move is also analyzed by using the developed model. For the assessment of the ecological value of the site, HEP (Habitat Evaluation Procedure) is employed, in which one of the typical species of bivalves is chosen as a target species. Water depth, sediment size, bottom friction velocity are chosen as the environmental factors for the target species. The suitable

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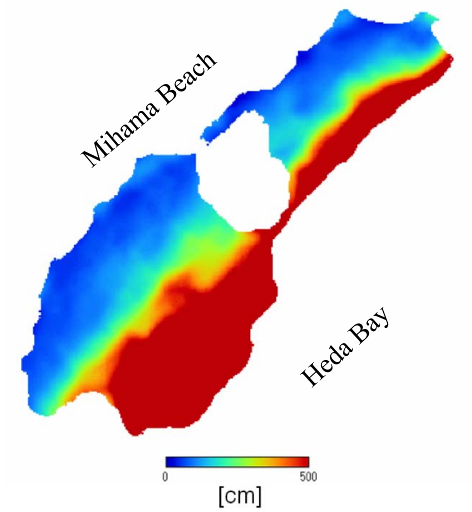


Fig. 2. Water depth in the vicinity of Mihama.

indices (SI) for each environmental factors are calculated by using the results of hydrodynamic and sediment transport simulations. By using the developed scheme, habitat value for the target site is evaluated for the proposed restoration plans and compared to the current value.

II. Field Measurements

The project team carried out field survey for water current, water quality, benthic quality, benthos and sessile organisms, and so on. Especially, for the purpose of developing and validating the models used in the present study, the following measurements is carried out.

The water depth in the vicinity of Mihama is measured by a combined system of GPS and high-accuracy sonar. The measured data is corrected by using the tide data and converted to the grid data. The obtained dataset is shown in Fig.2, which is used for the grid data of the current and sediment models as well as for the evaluation of SI in HEP.

Water current and wind are also continuously measured to obtain the validation data for the current simulation. The current roses at St.4 and St.5 (location is shown in Fig.1) during the observation period (19 Dec. 2008-14 Jan. 2009) are shown in Fig.3. It is found that the currents are quite weak in the vicinity of Mihama Beach. It is because the water body in front of the beach is surrounded by piers and banks.

III. Simulation Models

A. Current

MEC-NEST[2] is employed for current simulations. The basic equations are as follows; In the physical submodel, Cartesian coordinate system is adopted, and hydrostatic and Boussinesq approximations are assumed. The governing equations are the momentum equations in 3 directions and the

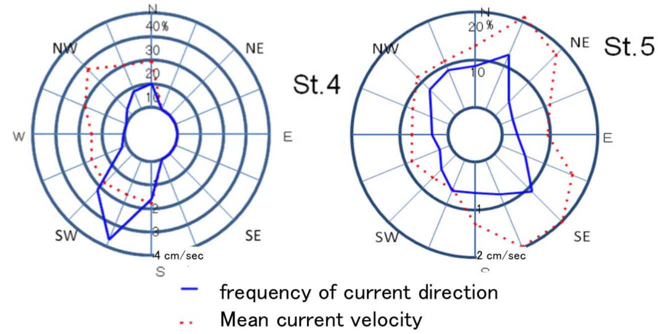


Fig. 3. Current roses at St.4 and St.5 for 19 Dec. 2008-14 Jan. 2009.

TABLE I
THE MODEL PARAMETERS USED IN THE SIMULATIONS.

Symbol	definition	value		unit
		rank1	rank2	
$\Delta x(y)$	horizontal grid size	18	6	m
Δz	vertical grid size	$0.5 \sim 10$		m
Δt	time interval	0.57	0.24	sec
A_M	horizontal eddy viscosity	0.47	0.11	m^2 sec^{-1}
K_M	vertical eddy viscosity	0.0001		m^2 sec^{-1}

equation of continuity;

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p_s}{\partial x} +fv+A_M\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_M\frac{\partial u}{\partial z}\right) \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p_s}{\partial y} -fu+A_M\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_M\frac{\partial v}{\partial z}\right) \quad (2)$$

$$0=-\frac{1}{\rho}\frac{\partial p}{\partial z}-g \quad (3)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (4)$$

where u, v, and w are three dimensional current veloities, p the pressure, ρ the density of seawater, f the Coriolis parameter, A_M and K_M the horizontal and vertical eddy viscosities.

The model parameters used in the simulations are shown in Table I.

B. Sediment

The equation for sediment transport is as follows;

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+(w+w_s)\frac{\partial C}{\partial z} =A_C\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_C\frac{\partial C}{\partial z}\right) +\frac{\partial E}{\partial z}-\frac{\partial D}{\partial z} \quad (5)$$

$$(6)$$

where C is the concentration of suspended sediment and w_s the sedimentation velocity. The the erosion rate E and the accumulation rate D are estimated as follows;

$$\left.\begin{array}{ll} E = M\left(\frac{\tau_b}{\tau_e} - 1\right) & (\tau_b \geq \tau_e) \\ E = 0 & (\tau_b \leq \tau_e) \end{array}\right\} \quad (7)$$

$$\left.\begin{array}{ll} D = w_s\left(1 - \frac{\tau_b}{\tau_d}\right) C_b & (\tau_b \leq \tau_d) \\ D = 0 & (\tau_b \geq \tau_d) \end{array}\right\} \quad (8)$$

where C_b is the near-bed sediment concentration and M is an empirical erosion rate constant. The bed shear stress τ_b, the critical bed shear stresses for deposition τ_d, and the critical bed shear stresses for erosion τ_e are calculated as follows[3];

$$\tau_b = \tau_c[1 + 1.2(\frac{\tau_w}{\tau_c + \tau_w})^{3.2}] \quad (9)$$

$$\tau_c = \rho_w C_d U^2 \quad (10)$$

$$\tau_w = \frac{1}{2}\rho_w f_w u_w^2 \quad (11)$$

where ρ_w is the density of seawater, C_d the drag coefficient, U the current velocity at the sea bottom, f_w wave frictional coefficient, and u_w wave orbital velocity at the sea bottom, which are determined by the following formulae.

$$C_d = \left(\frac{\kappa}{1 + ln\frac{Z_{ox}}{h}}\right)^2 \quad (12)$$

$$f_w = 1.39\left(\frac{A}{Z_{ox}}\right)^{-0.52} \quad (13)$$

where κ is the Kalman Coefficient (=0.4), Z_{ox} bottom surface roughness (= 0.05×10^{-3}), h the water depth, and A the amplitude of bottom orbital displacement.

The parameters used in the sediment model is shown in Table II.

Change of topography is also very important for the management of coastal environment. Thus a simple estimation of water depth change based on the sediment model is carried out. The change of water depth h due to sediment move is estimated by the following equation;

$$\frac{\partial h}{\partial t} = \frac{D - E}{\rho_s} \quad (14)$$

where ρ_{sd} is the density of sediment, which is assumed to be 2650 kg m^{-3} for all the sediment categories.

C. Computational Conditions

The comutational grid is shown in Fig.4. In order to analyze the phenomena in the vicinity of Mihama in detail, a nested grid system is employed. At the open boundary, four major constituents of tide are given. There are no suspended sediment at the initial condition, and the simulations are carried out for 10 days, when the THU (Total Habitat Unit) value become almost steady state.

D. Validation of the models

Figure 5 shows the tidal ellipses for semi-dirnal component. The simulation reproduces the features of the observed tidal currents.

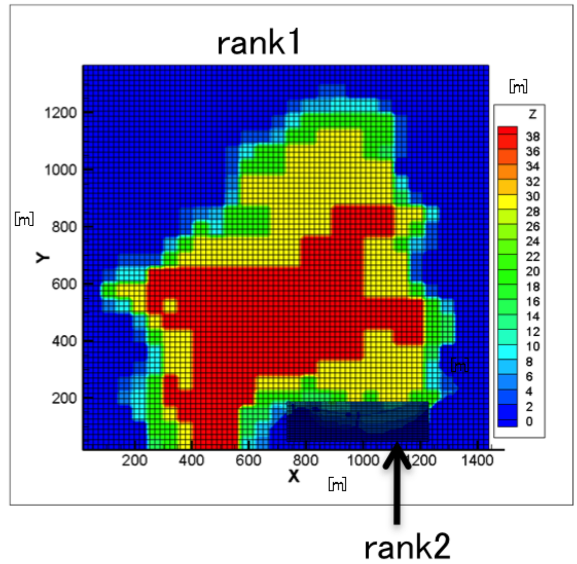


Fig. 4. Computational grid used for the simulations.

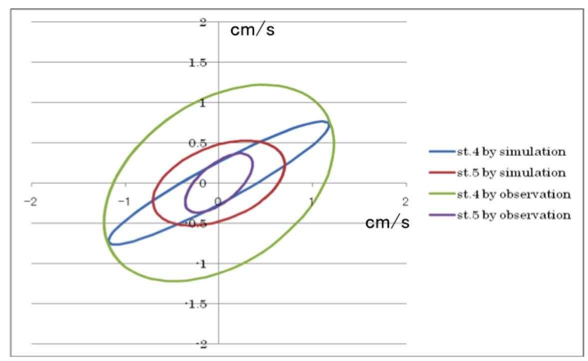


Fig. 5. Comparison of tidal ellipse between the simulation and measurement.

The calculated mean sediment size are also compared to the field measurement for several locations in the target area(Fig.6). The simulation reproduces the features of the distribution of the sediment size.

IV. Simulation-based Habitat Evaluation

A. Habitat Evaluation Procedure(HEP)

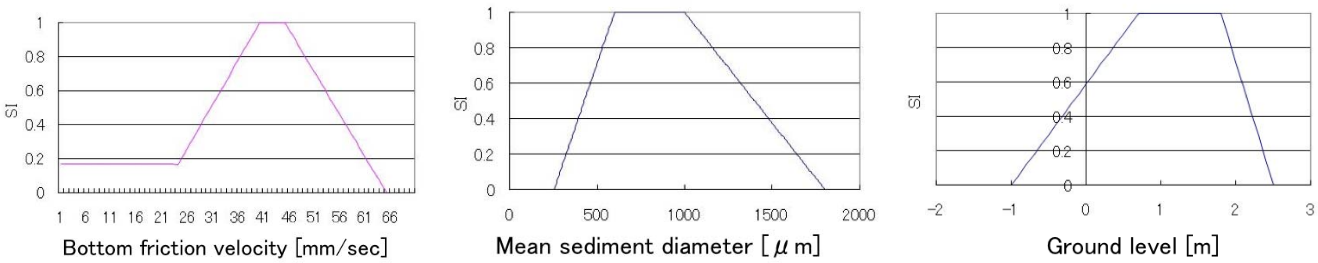
In order to assess the environmental value quantatively, Habitat Evaluation Procedure(HEP) is employed, which is a method to evaluate environmental values as habitat. As a target spiece, short necked clam is chosen. As environmental factors, bottom frictional velocity, sediment diameter, and water depth are chosen.

1) SI Model: The bottom frictional velocity, the sediment diameter, and the water depth are chosen as the environmental factors for HEP in the present study. The SI model of the target spiece (short-necked clam) for these factors are based on the preceding studies[5][6]. The bottom frictional velocity and sediment diameter is calculated by the hydrodynamic and sediment simulations.

TABLE II

THE PARAMETERS USED IN THE SEDIMENT MODEL[3][4].

Symbol	definition	sediment diameter[μ m] 100	300	500	800
w_s	sedimentation velocity [m s^{-1}]	0.004	0.035	0.070	0.100
τ_e	critical bed shear stress for erosion[kg m^{-1} s^{-2}]	0.13	0.20	0.25	0.40
τ_d	critical bed shear stress for deposition[kg m^{-1} s^{-2}]	0.13	0.20	0.25	0.40
M	constant for erosion rate	5×10^{-4}			



(a) (b) (c)

Fig. 7. SI(Suitable Index) models of short-necked clam for (a) bottom friction velocity, (b) mean sediment diameter, and (c) ground level[5][6].

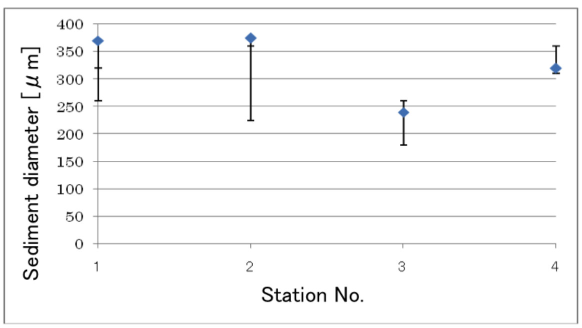


Fig. 6. Comparison of mean sediment size between the simulation and measurement.

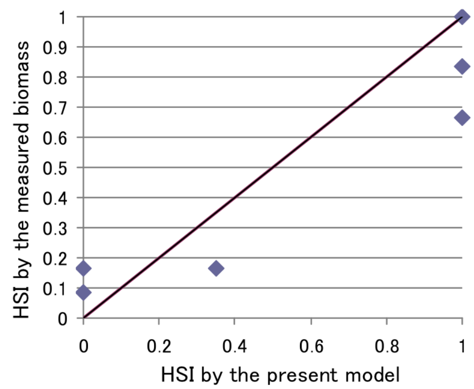


Fig. 8. Correlation between HSI values by the present model and by field observation.

2) HSI Model: The multiplication-type HSI model is employed for the target species;

$$HSI = SI_{bfv} \times SI_{msd} \times SI_{gl} \tag{15}$$

where SI_{bfv}, SI_{msd}, and SI_{gl} are the suitable indices of bottom frictional velocity, mean sediment diameter, and ground level, respectively.

3) Validation: In order to validate the employed HSI model, correlation of HSI values evaluated by the model and field survey is investigated(Fig.8). Since there are only poor habitat in the target site, the data in the different site[7] is used for the validation. It is clarified that the model results and field observation correlate fairly well.

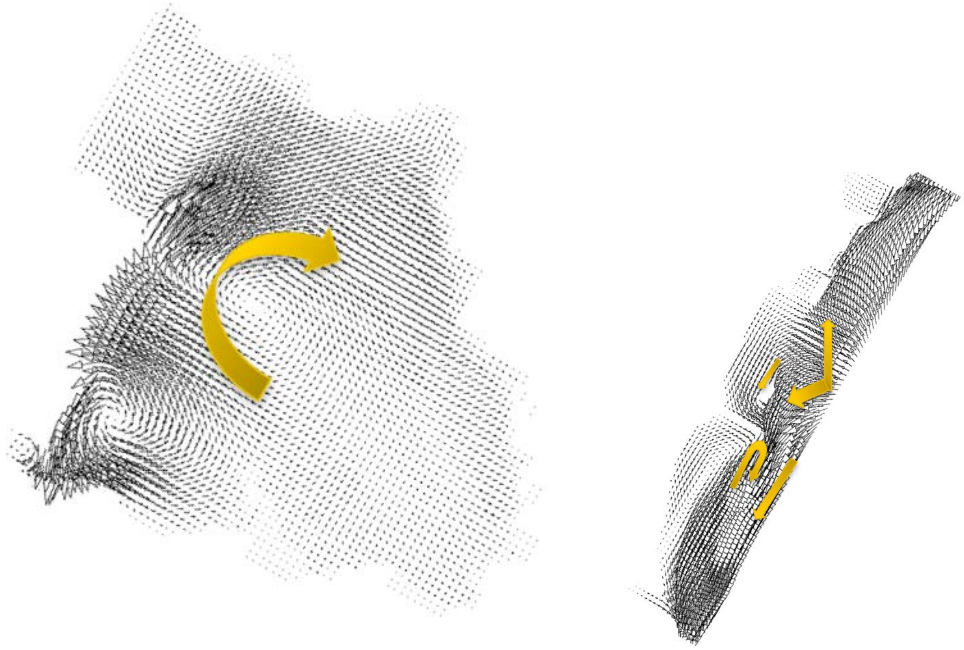
V. ASSESSMENT OF ENVIRONMENTAL RESTORATION PLANS

A. Simulation Results

Figure 9 shows the pattern of tidal residual current in the whole Heda Bay and that in the vicinity of Mihama obtained by the tidal current simulation. There is a clockwise circulation in the whole Heda Bay, which support conventional knowledge. In the vicinity of Mihama, very complicated pattern of tidal residual current is found. It is also found the current velocity inside the submerged bank is quite small.

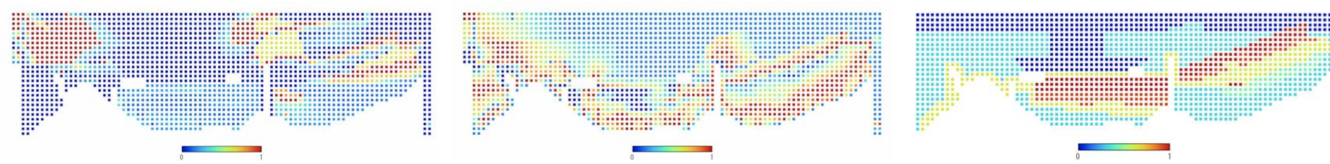
B. Calculation of SI and HSI

Figure 10 shows HSI map for the present status of target area. The results indicates that the habitat value for the target species are low in almost all the target area, which matches the present actual situation. Figure 11 shows the spatial distribution of SI for each environmental factors calculated from the simulation results. It is found that SI of sediment diameter takes small value in almost area, which indicates that the too fine sediment is the main cause for inadequate condition for the habitat of target species.



(a)whole Heda Bay (b)vicinity of Mihama

Fig. 9. Tidal residual current obtained by the simulation.



(a)mean sediment diameter (b)bottom frictional velocity (c)ground level

Fig. 11. Spatial distribution of SI based on the simulations and measurement.

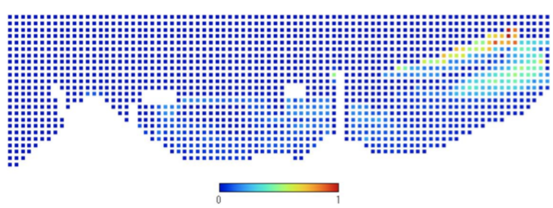


Fig. 10. HSI(Habitat Suitable Index) map for the present state.

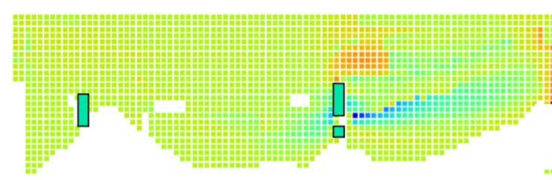


Fig. 13. Change of water depth predicted by the simulation.

C. Assessment of proposed plan

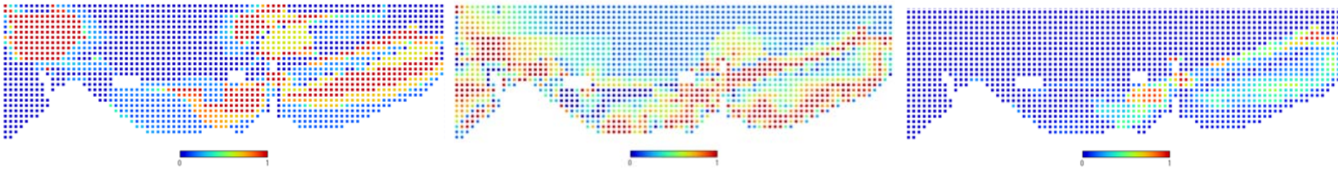
The scheme is applied to the assessment of proposed environmental restoration plan for Heda-Mihama(Case 1 in Fig.14). Figure 12 shows maps of SI and HSI for the proposed plan, in which two piers (only the near shore part for the central one) are removed. It is predicted that the removal of the piers will significantly increase the habitat value of the target site. It is because the water current is significantly increased which make the sediment size larger as well as promote the water exchange at the site. Figure 13 shows simulated topographical change. The sediment in front of the beach will be transported to the head of the beach.

D. Comparison of Alternative Plans

The method is also applied to assess the alternative plans shown in Fig.14. In these plans, not only the piers but also the banks will be removed. As an indicator, weighted averaged habitat suitable index (AHSI) is used, which is a normalized total habitat unit (THU) by the total target area;

$$AHSI = \frac{THU}{(\text{total area of target site})} \tag{16}$$

The obtained AHSI for each plans are shown in Fig.15. It is found that the plans removing banks don't always take high AHSI scores. Case 2 will provide most preferable habitat, in



(a)SI for mean sediment diameter (b)SI for bottom frictional velocity (c)HSI

Fig. 12. SI and HSI for the proposed restoration plan.

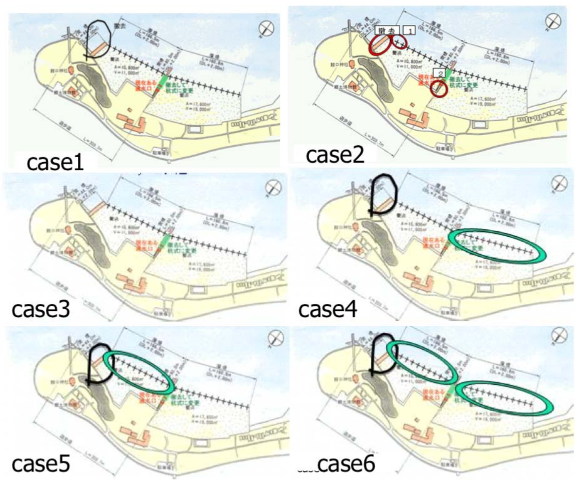


Fig. 14. Environmental restoration plans for Heda-Mihama. The piers and/or the banks in the circle will be removed.

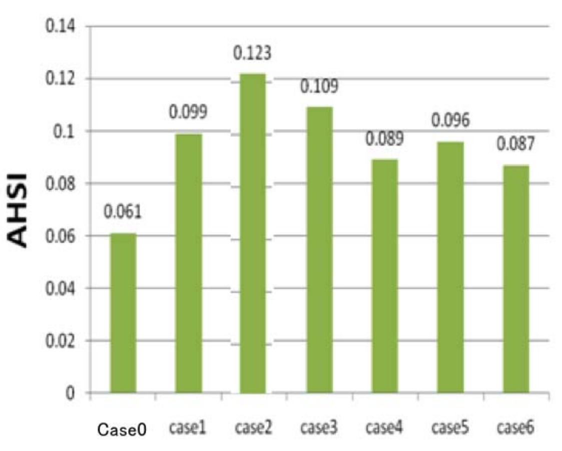


Fig. 15. AHSI for the environmental restoration plan predicted by the present method. Case 0 denotes the present state.

which a little part of the bank will be removed additional to the proposed plan.

VI. Conclusion

A simulation-based habitat evaluation approach is developed and applied to the assessment of environmental restoring plans for Heda-Mihama.

By using the developed scheme, habitat values are evaluated for the proposed restoration plans and compared to the current values. It is predicted that the removal of the piers will significantly increase the habitat value of the target site. It is because the water current is significantly increased which make the sediment size larger as well as promote the water exchange at the site.

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