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Integrated Hydraulic Modelling, Water Quality Modelling and Habitat Assessment for Sustainable Water Management: A Case Study of the Anyang-Cheon Stream, Korea

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Abstract: Recent ecological stream restoration projects have focused on expanding the water-friendly space of streams, promoting the health of aquatic ecosystems, and restoring various habitats, which raise the need for relevant research. Applying integrated environmental analysis, this study quantifies the change in hydraulic characteristics before and after the restoration projects through physical habitat simulation and links the results of physical impacts to estimate benefits of increase in water quality and aquatic ecosystem health due to the implementation of the project. For this, the study area is a 3.3 km long reach of the Anyang-cheon Stream, Korea. Field monitoring revealed that five fish species are dominant and sub-dominant, and account for 76% of the total fish community. To assess the change of before and after ecological stream restoration project, the River2D and Coastal Modelling System (CMS)-Flow 2D models were used for hydraulic and water quality simulations, respectively. For the habitat simulation, the HSI (Habitat Suitability Index) model was used. In addition, the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) was used to calculate changes in water quality index and to examine changes in habitat areas with an integrated quantitative index, the methodology of Zingraff-Hamed et al. was adopted. It was found that the ecological stream restoration project significantly increased for the eco-friendly area. In addition, the changes in water quality and habitat suitability grades before the ecological river restoration project were improved to two stages and one stage, respectively. This study applied the integrated analytical framework as a policy/project assessment tool and the results of this study will be useful for the integrated water management policy.

Keywords: ecological stream restoration projects; integrated environmental analysis; physical habitat simulation; CCME WQI; hydraulic habitat suitability

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1. Introduction

Streams have provided important space for human life from the past to the present, and are resources that have important environmental, ecological, and cultural values. The rivers are mostly made up of water and soil, providing a special ecological habitat space for aquatic species. However, in Korea, since the 1960s, the basic river management project has been performed for industrialization, and the channel-straightening and river maintenance of artificial levees has occurred. This resulted in the maximization of the water use and flood control, however the various changes in the aquatic ecosystem led to the decrease of biodiversity, aquatic ecosystem health, and suitable habitat area [1–4].

However, as part of the polluted rivers and urban development, various eco-friendly river restoration projects are carried out to improve the aquatic ecosystem health and habitat area. Previous studies performed that ecological river restoration project adversely affects the aquatic ecosystem health and habitat conditions [1–3]. Through the ecological stream restoration project, the habitat space and spawning space of aquatic species were secured due to changes in water depth and velocity, which provided an environment in which Korean native species and legal protected species could live. In Korea, the project was carried out to raise interest in improving and restoring the habitat of aquatic organisms and to form a consensus to restore the damaged rivers to their original shape.

The Ministry of Environment confirmed the effect of the ecological river restoration project of Yangjae-cheon Stream by applying the natural river restoration techniques i.e., restoring meanders to straightened rivers, dam removal, and step-pools and other grade-control structures etc. to sections of Yangjae-cheon Stream in Yangjae-dong, Seocho-gu, Seoul, Korea [4]. Seoul City has restored the waterfront space and the riverside space through various restoration techniques for the Cheonggye-cheon stream [5]. In addition, ecological river restoration projects were carried out to restore the environment and improve hydrophilicity in various streams, such as Seoho-cheon Stream, Gyeong-cheon Stream, Anyang-cheon Stream, and Hakui-cheon Stream [6]. In order to analyze the impact of the ecological river restoration project on aquatic habitat in rivers, various physical habitat simulations have been carried out recently and plans have been established. The effects of ecological river restoration projects are many previous studies, for example, the changes in environmental flow [7,8], the effect of dam removal [9–11], and the effect on life stages of aquatic species through river restoration techniques [12–18].

Predicting aspects of environmental changes due to internal and external changes is a very difficult problem due to uncertainty [19,20]. In addition, the previous study simulated only changes in aquatic ecosystem habitats due to physical and chemical changes in rivers without simulating changes in watershed unit water volume and water quality. Generally, in order to simulate the physical and chemical changes in the river with high accuracy, changes in the basin should be analyzed first and applied as boundary conditions that flow into the river. For this reason, rainfall-runoff model should be applied. The previous studies have been conducted to predict changes in the basin through rainfall-runoff model. The most common study of changes in the watershed is the study of changes in runoff according to rainfall patterns [21–24]. Regression equations through empirical and monitoring data are applied to predict the change of runoff, but recently, it is used to predict time and economic usefulness using AI-based method. In addition, there are previous studies on the changes in water quality due to the change in the amount of runoff [25–28]. The calculated return value can be applied through the watershed modeling in the basin to the boundary condition predicting inside of river the water quality change. Fourier analysis is generally used to predict various time series changes in the environment, but it is known that there is a problem in predicting time series analysis and trends. Therefore, recently, various environmental signals have been analyzed through wavelet analysis, and it is applied to various fields [29,30]. However, most previous physical habitat simulations have not taken integrating hydraulic, water quality, and habitat simulations into account when assessing the effect that the ecological river restoration project has on the aquatic habitat.

The present study aimed to investigate the effects of Ecological river restoration project. For this, a 3-km long reach of Anyang-cheon Stream was selected for the study area. Field monitoring revealed that five fish species are dominant and sub-dominant in the study reach and account for 76% of the total fish community [4–6,17]. The River2D model and CMS-Flow 2D model were used for hydraulic and water quality simulations, respectively. For the habitat simulation, using the method of Gosse [31], habitat suitability curves (HSCs) of individual species were constructed for each habitat variable. In addition, the changes in water quality grade and the qualitative and quantitative changes of habitats were compared and analyzed before and after the restoration project.

2. Study Area and Monitoring Data

Anyang-cheon Stream was called Daecheon, and since the late Joseon Dynasty, it was called Daecheon or Gitan, and recently it started to be called Anyang-cheon Stream. In the past, Anyang-cheon Stream was a meandering channel however river projects were implemented according to land use changes and urban development. In July 1977, many people and property losses occurred due to the flood, and in 1978, the basic plan for river maintenance was established and maintained. In the Figure 1, Anyang-cheon Stream is a river that flows through the downtown of Gunpo and Anyang City and flows into the Han River through Gwangmyeong City and Seoul City (N 126°54′11″ E 37°31′34″). The watershed area is 286 km^2, the length of the channel is 32.5 km, the average width of the watershed is 8.8 km, and the watershed shape coefficient is 0.271. The study area is 3.3 km long reach located in the middle of Anyang-cheon Stream. The average annual rainfall in the watershed is 1203 mm, and the design flooding for 200-year return period calculated by the river basic plan report is 2360 m^3/s. A land use for the study area was distributed to 55%, 15%, 12%, 7%, 5%, 4%, and 2% of the residential, commercial, industrial, forest and parks, river, agriculture, and parks, respectively. Most of Anyang-cheon Stream is completed for river improvement project, and some of the high water revetment is made of stones and environment-friendly materials. However most of the upstream areas were installed as concrete block. In the case of Anyang-cheon Stream, various problems are included in the basin, and various experts such as hydraulic, hydrology, water quality, ecology and urban planning field participated and established a comprehensive plan which is part of Anyang-cheon Stream Ecological Restoration Project. Anyang-cheon Stream Ecological Restoration Project can be classified into water quality improvement project, quantity securing project, natural river maintenance and ecological restoration project. Yangjae-cheon Stream is a representative example of ecological river restoration project in Korea. In the case of Yangjae-cheon Stream, not only has been in business for quite a long time, but the amount of data is relatively insufficient to simulate various changes caused by this project. In the present study, several conditions were set for selecting the target study area. First, it was a project carried out in the 2000s, in a river no older than 20 years. It is not a tributary section that flows into the main stream, but it is located in the metropolitan area or nearby area. In addition, the river is a river that flows into a large main stream of medium size or larger, and it is possible to secure some data on quantity, water quality, and aquatic ecosystem. The study was conducted on Anyang-cheon Stream because Anyang-cheon Stream was satisfied with the conditions.

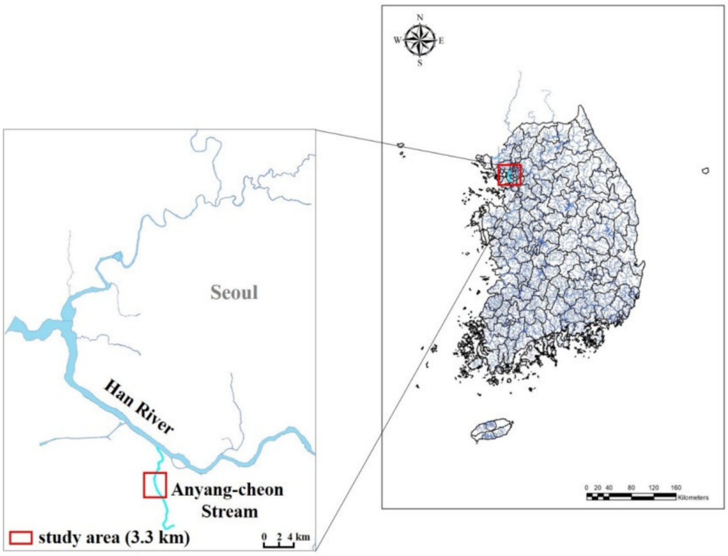


Figure 1. Study area.

In the study area, on-site monitoring of fish was conducted as part of river restoration project. In addition, in the present study reach, for the 2000–2018 periods, hydrologic data and monitoring data were collected through government R&D projects [4–6,17]. The monitoring data include date, flow depth, velocity, substrate, water quality, and population of the individual fish species. To measure the velocity and water surface elevation, devices such as the Price current meter and radar water gauges were used, respectively. Fish monitoring was carried out using the cast nets and kick nets. As a result, the results of the study were distributed to 27%, 15%, 15%, 11%, and 8% of the *Zacco koreanus*, *Zacco platypus*, *Coreoleuciscus splendidus*, *Pungtungia herzi*, and *Acheilognathus yamatsutae*, respectively. As a result of on-site monitoring, there are five species of dominant species and sub-dominant species, which correspond to about 76% of target species. In the present study, we performed physical habitat simulations on five dominant and sub-dominant species to understand the effects of ecological river restoration projects on habitat.

3. Methods

3.1. Hydraulic and Water Quality Simulations

For hydraulic simulation, the River2D model was used in the present study. The model was developed by Steffler and Blackburn at the University of Alberta in the Canada [32]. The River2D model solves two-dimensional depth-averaged hydrodynamic equations using the finite element method [32]. The River2D model is composed of grids using a non-aligned triangular interpolation method and numerically analyzed using finite element method. The continuity and momentum equations in the x-y horizontal plane are given by the following, respectively.

$$\frac{\partial H}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=0 \tag{1}$$

$$\frac{\partial q_x}{\partial t}+\frac{\partial}{\partial x}(Uq_x)+\frac{\partial}{\partial y}(Vq_x)+\frac{g}{2}\frac{\partial H^2}{\partial x}=gH\left(S_{0x}-S_{fx}\right)+\frac{1}{\rho}\left\{\frac{\partial}{\partial x}(H\tau_{xx})\right\}+\frac{1}{\rho}\left\{\frac{\partial}{\partial y}(H\tau_{xy})\right\} \tag{2}$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial}{\partial x}(Uq_y)+\frac{\partial}{\partial y}(Vq_y)+\frac{g}{2}\frac{\partial H^2}{\partial x}=gH\left(S_{0x}-S_{fy}\right)+\frac{1}{\rho}\left\{\frac{\partial}{\partial x}(H\tau_{yx})\right\}+\frac{1}{\rho}\left\{\frac{\partial}{\partial y}(H\tau_{yy})\right\} \tag{3}$$

where t is the time, x and y are the stream-wise and transverse directions, respectively, H is the flow depth, U and V are the depth-averaged velocities in the x- and y-directions, respectively, $q_x(=HU)$ and $q_y(=HV)$ are respective unit discharges x- and y-directions, respectively, S_{0i} and S_{fi} are the friction slope in the x- and y-directions, respectively, g is the gravitational acceleration, ρ is the water density, and τ_{ij} is the horizontal stress tensor. The x and y components of the friction slope are respectively estimated by,

$$S_{fx}=\frac{n^2U\sqrt{U^2+V^2}}{H^{4/3}} \tag{4}$$

$$S_{fy}=\frac{n^2V\sqrt{U^2+V^2}}{H^{4/3}} \tag{5}$$

where Cs is a dimensionless Chezy coefficient, which is related to the effective roughness height (k_s). In the River2D model, both the Manning's n and effective roughness height are available, however in the case of actual rivers with various riverbed heights, it is known that applying effective roughness height can reflect the changes of riverbed frictional slopes better [32]. For the flow model test, the Manning's n and effective roughness height of the actually measured Manning's n were converted, and as a result, the effective roughness height was 0.80–1.52. The validation of simulation model was performed. The results of the validation were compared with the results of the measured flow depth. The measured data of the velocity and flow depth were used provided by Anyang-cheon Stream Ecological Restoration Report [33] and Han River Flood Control Center. As a result, the flow model used in the present study was very well matched with the measured value (see Figure 2). To quantitatively examine, MAPE (mean average percent error) was analyzed. When the measurement data and the computed data were compared, the error rate was less than 0.5%.

In the present study, the CMS-Flow 2D model was used to simulate changes in water quality [34]. The governing equations used in flow analysis is the same as the previous River2D model, and water quality analysis was performed by applying the flow depth and velocity of each node, which is the result of River2D model analysis, to the CMS-Flow 2D model. In order to simulate changes in water quality, the changes in water quality were simulated by considering factors that could cause changes in water quality in the study area such as changes in water quantity, changes in land coverage, and various water purification facilities in the basin through Geographic Information System (GIS) data before and after the ecological river restoration project [4–6,33]. This was used to control various factors that could occur through ecological river restoration projects and to use them as variables. Finally, it was used to simulate the effects of changes in quantity and water quality on habitats. In the case of the water quality model, the data of the water quality factors measured in the Anyang-cheon Stream Ecological Restoration Report [33] were used to validation, and the comparison was carried out before and after the ecological river restoration project. As a result, the model in the present study was well predicted before and after the restoration project. Basically, the comparison was performed on dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). As a result, all water quality factors showed errors within 2%. This indicates that the numerical model is capable of simulating short-term and long-term flows and water quality.

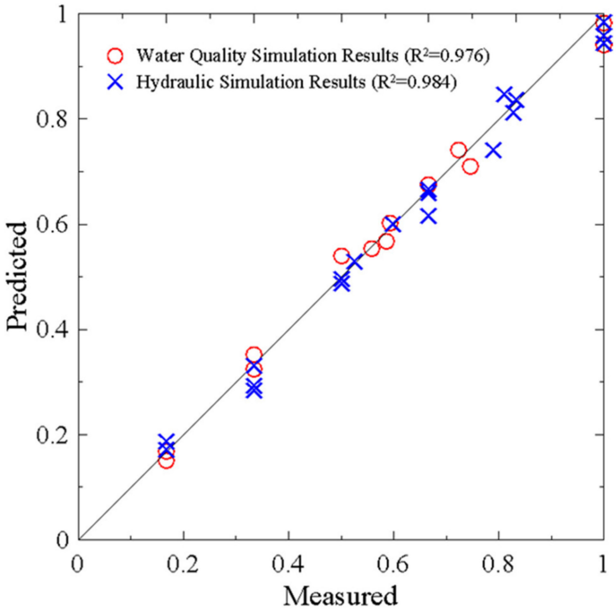


Figure 2. Validation for hydraulic simulation and water quality simulation results.

3.2. Habitat Simulation

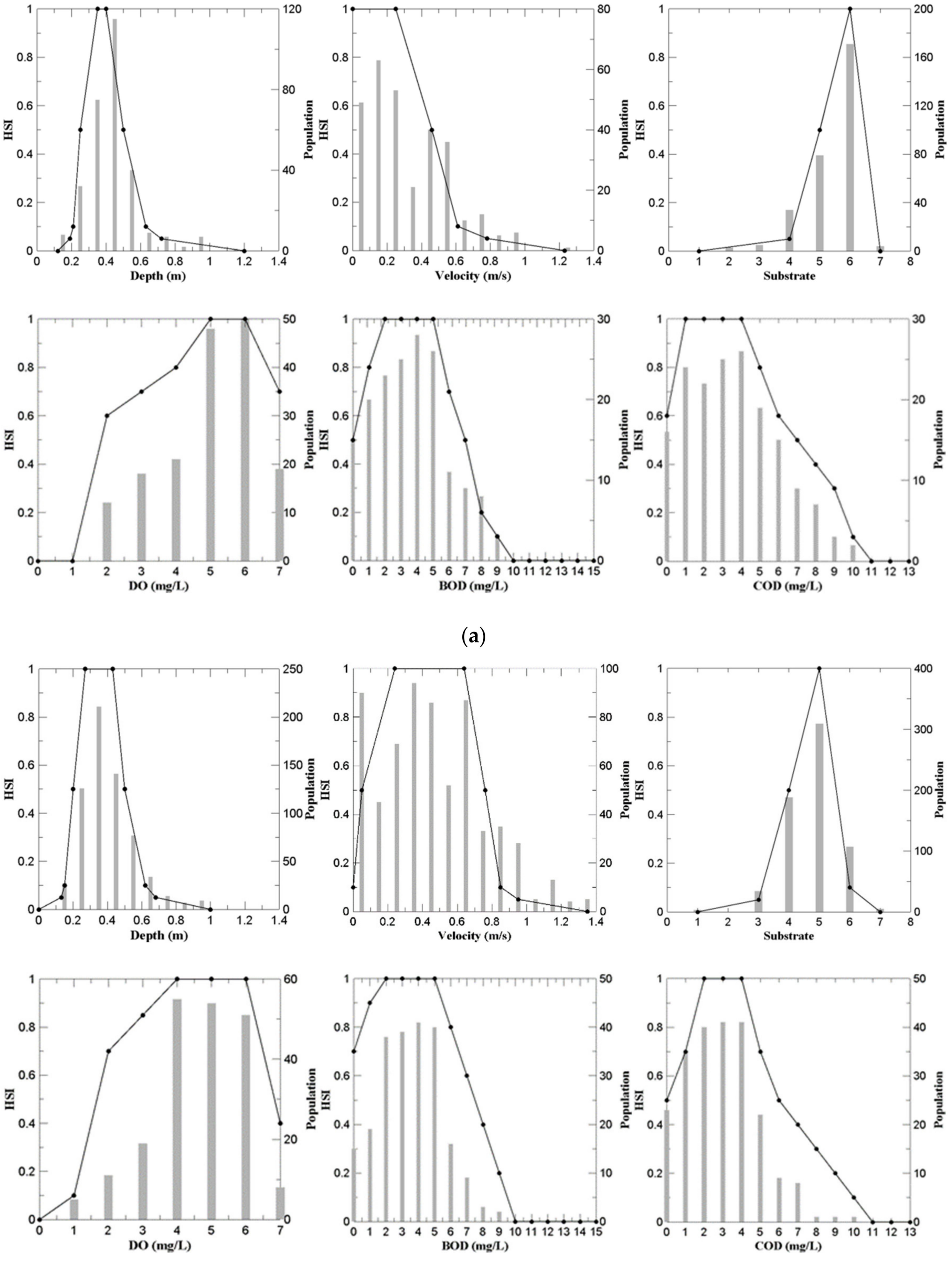
In the present study, habitat suitability index (HSI) model was used to analyze habitat for the target fish species. The HSI model is a method of constructing the habitat suitability curve (HSC) of habitat variables such as flow depth, velocity, and substrate, and describing the relationship between habitat variables and the suitability. In this study, the composite suitability index (*CSI*) was calculated by multiplicative aggregation method, and it was used to calculate the weighted usable area (*WUA*) which quantitatively shows the area of habitats occupied by target fish species in the study area [8–11]. The following equations were used for the *CSI* and *WUA* in this study.

$$CSI_i = f_v(v_i) \times f_H(H_i) \times f_s(s_i) \tag{6}$$

$$WUA = \sum_{i=1}^{n} A_i \times CSI_i = f(Q) \tag{7}$$

where $f_v(v_i)$, $f_H(H_i)$, $f_s(s_i)$ are the suitability index for flow depth and velocity, and substrate and Q is the discharge, and A_i and CSI_i are the area and composite suitability index of the ith computation cell, respectively.

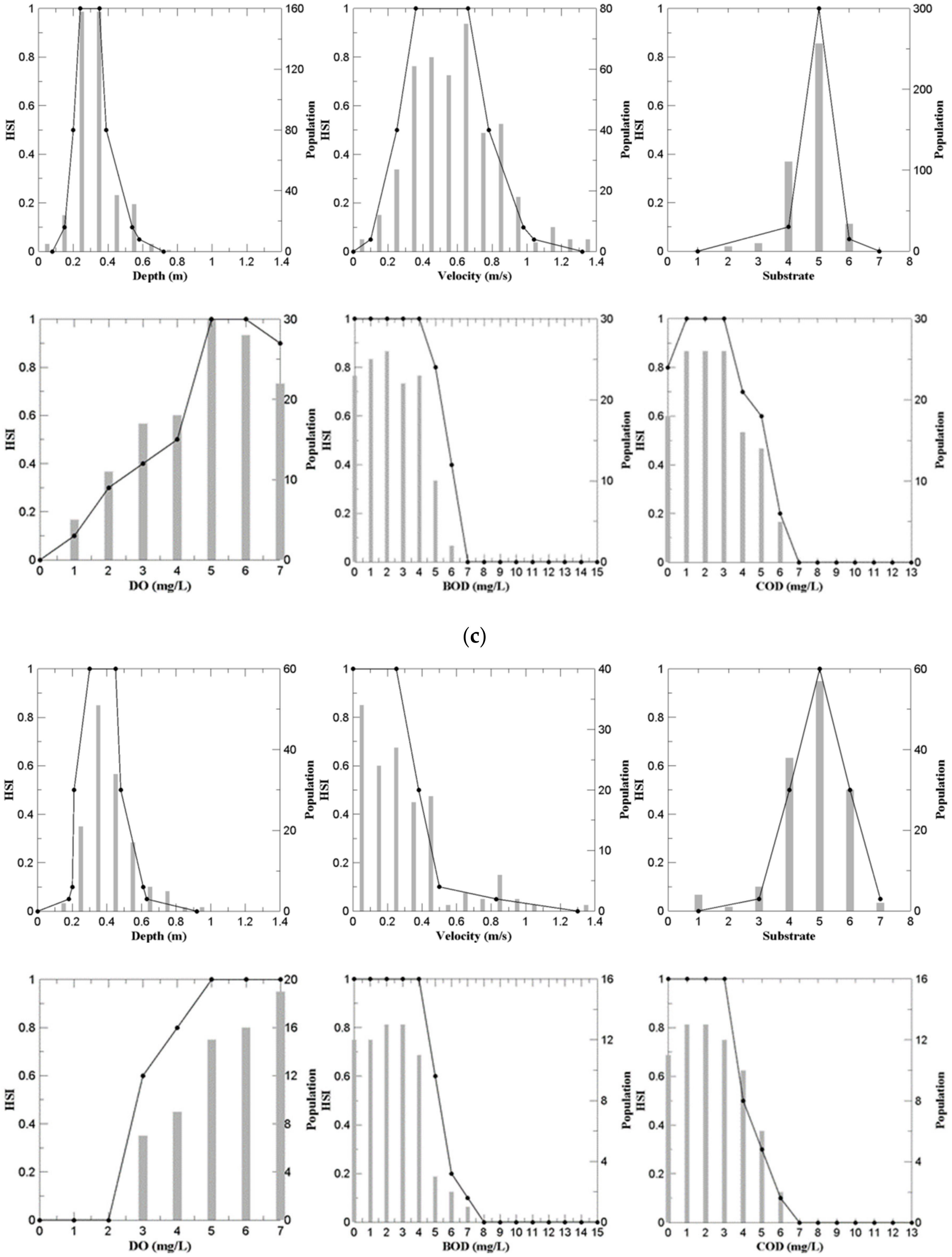
In the present study, we constructed an HSC for each physical habitat variable of target fish species by applying the method of Gosse [31]. This method sets the range for each physical habitat variable condition in the aquatic on-site monitoring data and then summarizes the population, and gives the values of habitat suitability indexes 1.0, 0.5, 0.1, and 0.05 to the range of variable that encompasses 50%, 75%, 90%, and 95% of the total target fish population. For the physical and chemical variables, the HSCs for the target fish species constructed by the method of Gosse [31] are given in Figure 3.



(**a**)

(**b**)

Figure 3. *Cont.*



(**c**)

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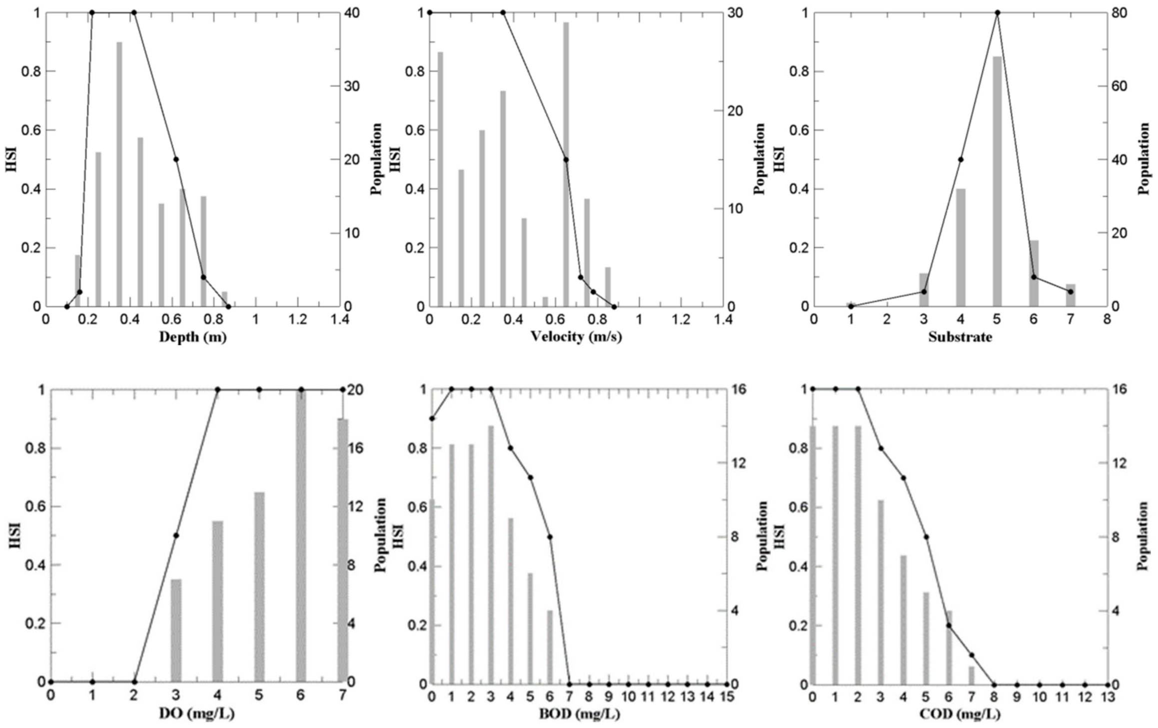


(**e**)

Figure 3. Habitat suitability curves for target species: (**a**) Zacco koreanus; (**b**) Zacco platypus; (**c**) Coreoleuciscus splendidus; (**d**) Pungtungia herzi; (**e**) Acheilognathus yamatsutae.

The HSI is distributed between 0 and 1, where 0 means that the habitat conditions of the target fish species are unsuitable habitat and 1 is optimal habitat. The bar graph means the population of the target fish species distributed within the corresponding range. The habitat conditions and characteristics of the target fish species can be understood by looking at the optimal conditions of the habitat variables through the HSCs. For the *Zacco koreanus*, *Pungtungia herzi*, and *Acheilognathus yamatsutae*, the preferred ranges were 0.22–0.45 m and 0.00–0.35 m/s for flow depth and velocity, respectively. Additionally, for the *Zacco platypus* and *Coreoleuciscus splendidus*, the preferred ranges were 0.15–0.43 m and 0.18–0.66 m/s for flow depth and velocity, respectively. The flow depth is found to be distributed in a relatively narrow range than the velocity, and it is expected that the change of habitat suitability will be greatly affected according to the velocity conditions. For the substrate, the HSCs for the target fish species constructed by the method of Wentworth [35]. The x-axis in the Figure 3 means grain classification. The number presented on the x-axis is clay (1), silt (2), coarse silt (3), fine sand (4), medium sand (5), coarse sand and granule (6), pebble and cobble (7), and boulder (8). The substrate of the study area consists of sand and gravel [4,6], so the habitat suitability is revealed to be nearly not affected by the substrate. That is, the stream substrate was not included in the analysis as the target species do not have a clear substrate preference. In addition, the HSCs for each target fish species were constructed for the chemical variables such as DO, BOD, and COD. For the *Zacco koreanus*, the optimal ranges were 5–6 (good), 2–5 (good to normal), and 1–4 (very good to slightly good) for DO, BOD, and COD, respectively. For the *Zacco platypus*, the optimal ranges were 4–6 (slightly bad to good), 2–5 (good to normal), and 2–4 (good to slightly good) for DO, BOD, and COD, respectively. For the *Coreoleuciscus splendidus*, the preferred ranges were 5–6 (good), 0–4 (very good to normal), and 1–3 (very good to good) for DO, BOD, and COD, respectively. For the *Pungtungia herzi*, the preferred ranges were 5–7 (good), 0–4 (very good to normal), and 0–3 (very good to good) for DO, BOD, and COD, respectively. For the *Acheilognathus yamatsutae*, the optimal ranges were 4–7 (slightly bad to good), 1–3 (very good to slightly good), and 0–2 (very good) for DO, BOD, and COD, respectively. In the case of DO, the target fish species preferred at the normal or good stage. In addition, for the BOD and COD, *Coreoleuciscus splendidus*, *Pungtungia herzi*, and *Acheilognathus yamatsutae* were relatively preferred to clean water quality except for the *Zacco koreanus* and *Zacco platypus*. Apparently, the change in physical and chemical due to ecological river restoration project is expected to affect both CSI and WUA for the target fish species.

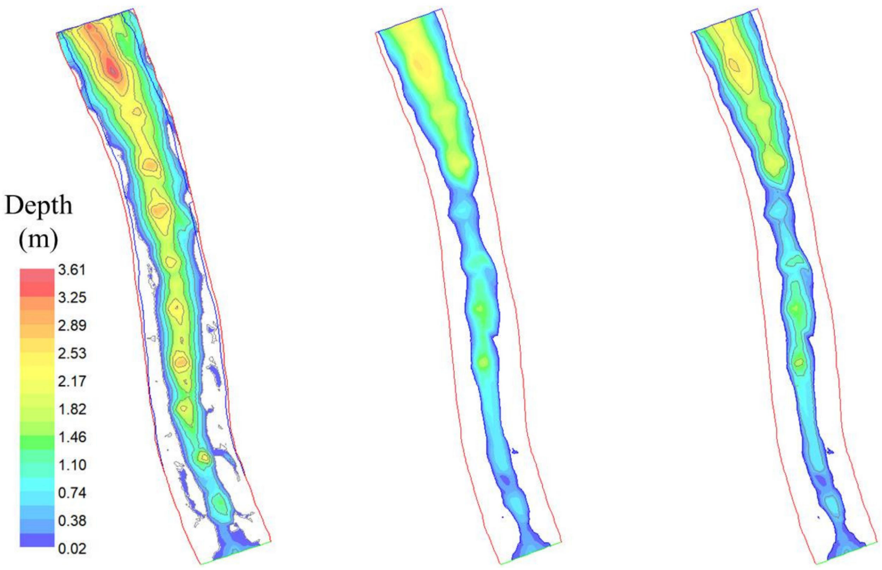
4. Results and Discussion

4.1. Hydraulic Simulation

Figure 4 shows the hydraulic simulation results (Q = 5 m^3/s) before and after ecological river restoration project. The reason for simulating the discharge of 5 m^3/s is that the environmental discharge, which is the maximum WUA of the target fish species. The flow results of the study area shows that the flow characteristics of the restoration project have changed significantly due to the topographical changes before and after the restoration project. Before the restoration project, the flow depth in the river range was more than 1.5 m and the velocity was more than 1.0 m/s. However, after the restoration project and present, the distributions are distributed 0.02–1.0 m and 0.0–0.7 m/s for flow depth and velocity, respectively. This indicates that the flow characteristics change effect increased the number of water-friendly space. The results also indicate that the change of the flow characteristics affects both the water quality of the stream and the habitat of the living aquatic species.

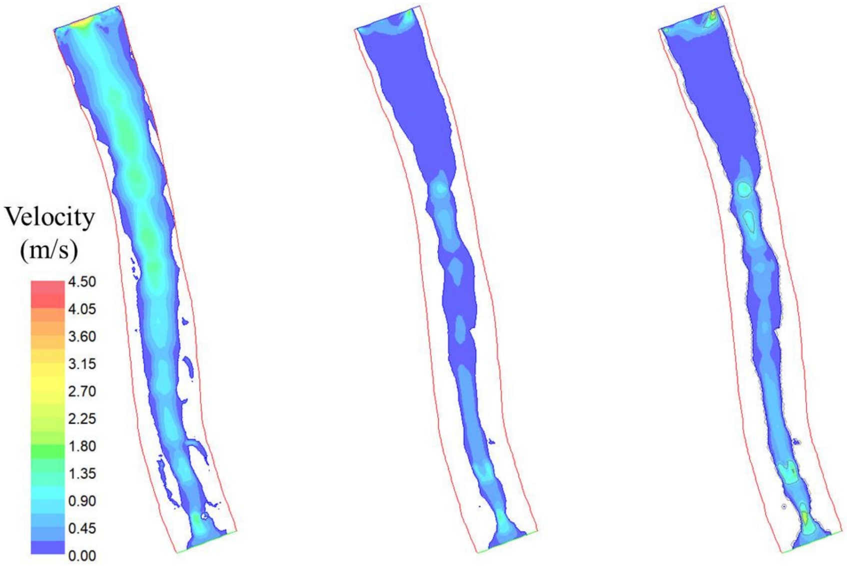
4.2. Water Quality Simulation

Figure 5 shows that the change of water quality (DO, BOD, COD) before and after ecological river restoration project. Water quality modeling was calculated using changes in flow depth, velocity, water temperature, thermal Prandtl number, and net heat exchange between the water column and its surroundings. The computed water quality is averaged over the study area. It can be seen in Figure 5 that, in general, the ecological restoration project significantly increased water quality. Specifically, DO was 0.8 mg/L (very bad stage (VI)) before the restoration project, and it was greatly improved to 4.9 mg/L (slightly good stage (II)) after the restoration project. In case of BOD, it was 14.8 mg/L (very bad stage (VI)) before restoration project, and 3.2 mg/L slightly good (II) or the normal (III) stage after restoration project, which was greatly improved like DO. Finally, COD was 12.3 mg/L (very bad stage (VI)) before the restoration project, and 4.4 mg/L (good stage (Ib)) after the restoration project. This was improved from the very bad stage (VI) to the good stage (Ib). Quantitatively, the ecological river restoration project increases the water quality by 512%, 363%, and 180% for DO, BOD, and COD, respectively. It is very important to represent water quality variables as an integrated indicator. There are many methods to represent various indicators as one factor, however the most commonly used method is CCME WQI [36–38]. Before the ecological river restoration project, the final score was calculated as 55.59 points when applying CCME WQI, which corresponds to the Marginal Water Quality. However, after the ecological river restoration project, 88.56 points were calculated as Good Water Quality. In the present case, there is no significant change in each water quality item, so when applying this methodology, Good Water Quality is satisfied and the water quality grade is maintained. In conclusion, when the water quality was finally graded and expressed, the water quality grade was improved by two stages from Marginal Water Quality to Good Water Quality due to ecological river restoration project.



before (2001) after (2006) present (2018).

(**a**)



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(**b**)

Figure 4. Distributions of flow modelling results: (**a**) distribution of flow depth; (**b**) distribution of velocity.

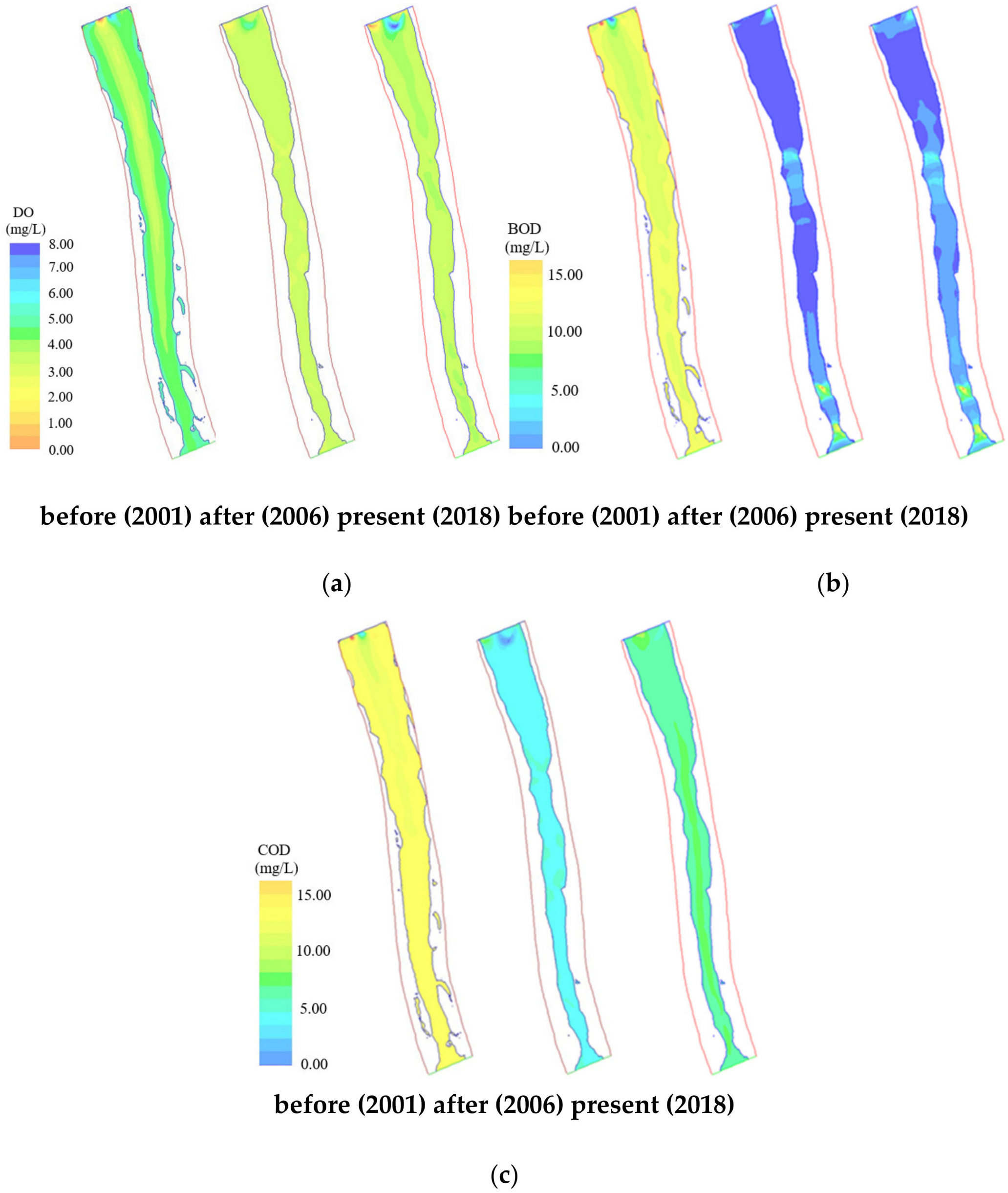
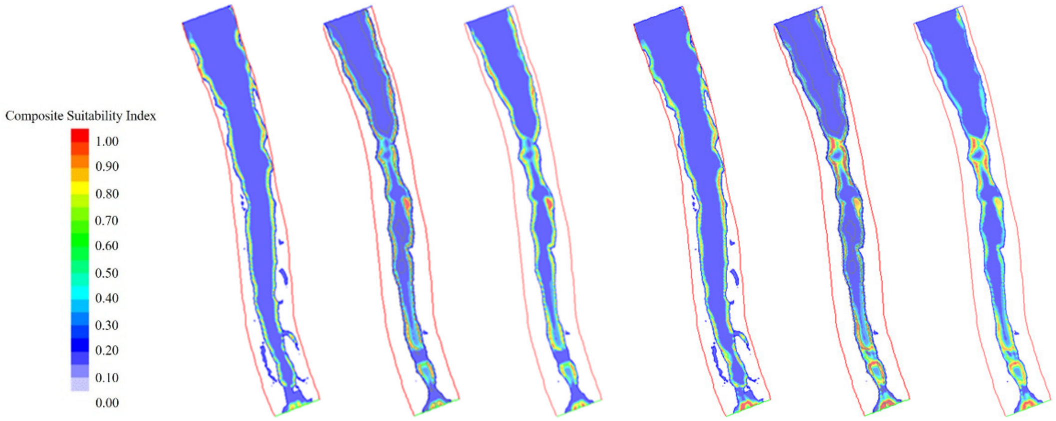


Figure 5. Distributions of water quality results: (**a**) DO; (**b**) BOD; (**c**) COD.

4.3. Changes in the Composite Suitability Index and Weighted Usable Area

Figure 6 shows the CSI distributions for the target fish species before and after ecological river restoration project. As can be seen in the figure shows that the ecological river restoration project significantly increased the CSI. This is because various river restoration techniques have been applied through ecological river restoration projects, and water quality has been purified through water quality improvement projects. This also indicated that the changes in flow and water quality due to the ecological river restoration project are in the preference range of the target fish species.



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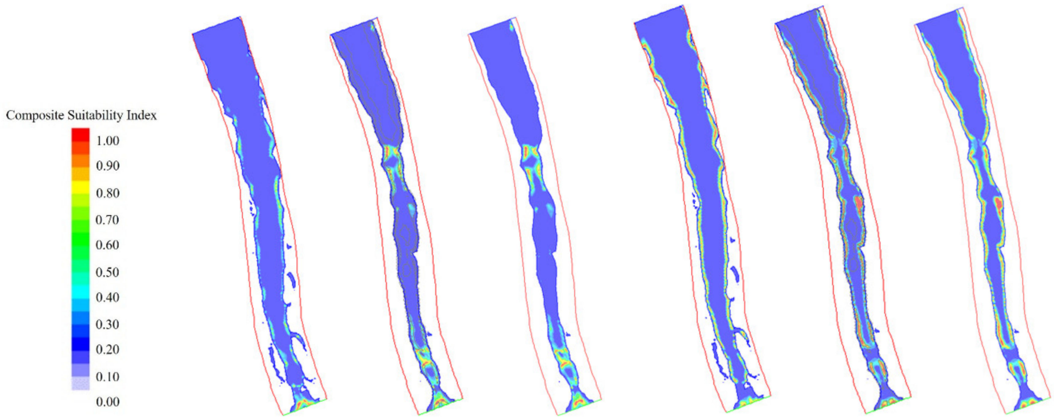
(**a**) (**b**)



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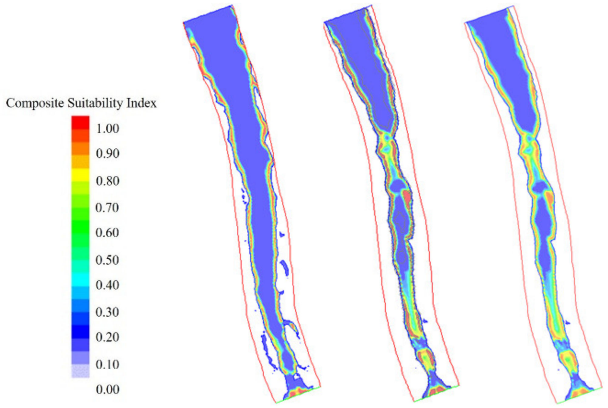
(**c**) (**d**)



before (2001) after (2006) present (2018)

(**e**)

Figure 6. The composite suitability index distributions for the target species: (**a**) *Zacco koreanus*; (**b**) *Zacco platypus*; (**c**) *Coreoleuciscus splendidus*; (**d**) *Pungtungia herzi*; (**e**) *Acheilognathus yamatsutae*.

Table 1 presents the change of the WUA before and after ecological river restoration project for target fish species. It can be seen that the ecological river restoration project significantly increased the WUA for the target fish species. Quantitatively, the ecological river restoration project increases the WUA by about 76.54%, 45.69%, 138.91%, 65.19%, and 86.14% for *Zacco koreanus*, *Zacco platypus*, *Coreoleuciscus splendidus*, *Pungtungia herzi*, and *Acheilognathus yamatsutae*, respectively. To examine the change of grade according to the change of habitat area, we can show it using the method proposed by Zingraff-Hamed et al. [1]. For simplicity, if a typical rule set with HHS (hydraulic habitat suitability) if-then rules are listed, then

Table 1. Target species and their weighted usable Area and hydraulic habitat suitability.

Target Fish Species	**Total Area (m^2)**	**Weighted Usable Area (m^2)**		
		Before (2001)	**After (2006)**	**Present (2018)**
Zacco koreanus	144,047	5844	10,317	10,003
Zacco platypus		6653	9693	9433
Coreoleuciscus splendidus		1542	3684	3781
Pungtungia herzi		6430	10,622	11,054
Acheilognathus yamatsutae		9902	18,432	16,041
Total Weighted Usable Area		30,371	52,748	50,312
HHS Index		21.08% (low)	36.62% (medium)	34.93% (medium)

- Rule 1: if (the ratio of the total area and the WUA of the target species > 80%) then (HHS = very high)
- Rule 2: if (50% ≤ the ratio of the total area and the WUA of the target species ≤ 80%) then (HHS = high)
- Rule 3: if (30% ≤ the ratio of the total area and the WUA of the target species ≤ 50%) then (HHS = medium)
- Rule 4: if (10% ≤ the ratio of the total area and the WUA of the target species ≤ 30%) then (HHS = low)
- Rule 5: if (the ratio of the total area and the WUA of the target species < 10%) then (HHS = very low)

By applying this method, the grade of the study area was improved from low to medium before the ecological river restoration project. As of 2018, the habitat area for the target fish species decreased somewhat than after the ecological river restoration project, however, the grade has been maintained. This indicates that the ecological river restoration project has a significant effect on habitat suitability for the aquatic species.

5. Conclusions

This study conducted physical habitat simulations to investigate the impact of water quality and habitat before and after ecological river restoration project. The study area is a 4.3 km long reach located Anyang City, Republic of Korea. Fish monitoring data revealed that five species, namely *Zacco koreanus*, *Zacco platypus*, *Coreoleuciscus splendidus*, *Pungtungia herzi*, and *Acheilognathus yamatsutae*, are dominant and sub-dominant, accounting for 76% of the total fish community. The River2D and CMS-Flow 2D models were used to predict the flow and water quality, and the HSI model was used for the habitat simulation. Six habitat variables, namely flow depth, velocity, substrate, DO, BOD, and COD, were used in the physical habitat simulations.

First, the changes in the hydraulic characteristics showed that the flow depth and velocity distributions were significantly changed before and after the ecological river restoration project. Before the project, the flow depth was more than 1.5 m and the velocity was more than 1.0 m/s. However, the flow depth was distributed between 0.02 and 1.0 m and the velocity was less than 0.7 m/s after the ecological river restoration project. For the water quality, before the ecological river restoration project of the study area, the water quality was deteriorated due to the environment where fish cannot live. However, after the project, the factors of DO, BOD, and COD were 512%, 363%, and 180% improved. In addition, the integrated water quality index method was applied to show the results of each water quality factor as an indicator. As a result, the water quality grade was improved by two stages due to the ecological river restoration project. In addition, the changes in habitats for fish community were performed. As a result, the WUA for fish community was improved by about 82.5% due to ecological river restoration project. When this was shown as a change in grade, compared to the result for the previous level of habitat suitability, the results were improved by 1 step from low grade to medium grade before the ecological river restoration project.

These results can be used as basic data for supporting water management policy to manage water quality, water quality, and aquatic ecology as an integrated system. In addition, it is considered that it will be an important indicator to set the direction considering both quantity, water quality, and aquatic ecology when the ecological river restoration project is carried out in the local government. Recently, in Korea, an important bill to integrate water quantity, water quality, and aquatic ecology has been initiated for the purpose of integrating water management. The present study analyzed the integrated water management through the ecological river restoration project that was conducted in the past. With these results, it is expected that the effect of changes in water quantity and water quality on aquatic ecology through the ecological river restoration project will be analyzed and it will be helpful when planning various projects in the future. This present study is a case study through one case, and there is a limit that the predictions in the future are not included. Therefore, it is necessary to analyze climate change scenarios, water quantity, water quality, and aquatic ecology, which are some of the major concerns.

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