Adaptive Management of the Post-Restoration in the Kamisaigo River

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ABSTRACT

The third-stage restoration of the Kamisaigo River in Fukutsu City has been completed within an urban–agricultural landscape. Through seasonal and long-term monitoring, adaptive management was identified as a crucial strategy for addressing the uncertainties in river restoration. The approach was implemented at the reach scale, where a new model was developed. The purpose of this research is to evaluate and verify the success of the river restoration project over time by assessing the changes in site indicators using the Fish Biological Health Index (FBHI). Following the completion of restoration measures across all reaches, evidence indicated that adaptive management, through the partial reconfiguration of the reach by adding logs and vegetation, had positively influenced river function. According to the biological health assessment, the FBHI values in the third year of restoration demonstrated good to excellent conditions which supported well-adapted species. Continued adaptive management was considered necessary to enhance the conditions in some stations with the goal of improving their biological health from good to excellent. The incorporation of spawning muddy-bottom habitats was proposed as a future research direction to support the ongoing adaptive management efforts. The FBHI is considered a valuable tool for assessing adaptive management performance. To achieve the restoration objectives, it was emphasized that the monitoring program should be maintained regularly, the recent outcomes should be reviewed, and timely adjustments should be applied based on identified shortcomings.

Keywords-adaptive management; monitoring; Fish Biological Health Index (FBHI)

I. INTRODUCTION

Adaptive management is an innovative approach that treats management programs as experiments. It establishes a direct feedback loop between science and management, allowing policy decisions to be informed by the best available scientific evidence at every stage of development [1]. This approach enables management decisions to be revisited and revised as new information becomes available [2]. Often described as "learning by doing," adaptive management views policy and management interventions in natural systems as opportunities for experimentation and learning [3]. Its effectiveness can be evaluated by assessing what has been learned and how management strategies have evolved in response to new knowledge. Adaptive management acknowledges that actions must often proceed despite the incomplete understanding of the system and the potential effects of interventions [4]. Authors in [5] highlighted a significant variation in how practitioners define adaptive management. Common interpretations include: acting thoughtfully and reassessing whether the objectives are being met, learning from mistakes, applying responsible risk-taking, repairing damage, and maintaining a willingness to modify actions if the results are unsatisfactory. Practitioners also emphasize defining clear, testable hypotheses for each action and designing projects with monitoring systems that can answer specific scientific questions. In the reviewed case studies, adaptive management was most frequently implemented at the sub-river spatial scale, such as the site or reach level. Despite the wide variation in definitions and applications, three key elements were consistently shared across projects: the recognition of uncertainty in river restoration and management, a strong commitment to systematic monitoring, and a readiness to adjust actions based on the insights gained from the observed outcomes.

Monitoring is a key effort of adaptive management and can provide recommendations to improve future efforts [3]. There is an essential importance of designing the monitoring program for adaptive management. The monitoring objective is a part of evaluating and identifying the river's status before and after restoration. Throughout monitoring and assessing river restoration, both negative (unexpected) and positive effects can also be detected, indicating how successful the river is after restoration. Authors in [6] revealed that for many years, biological data were viewed as too variable to be used in monitoring and assessment. When formulated and applied correctly, however, multi-metric biological indices substantially reduce this problem. Four key practices should be followed: comparing ecologically similar sites, selecting only the most reliable and responsive metrics, maintaining high data-quality standards, and using the power derived from combining multiple metrics. Monitoring, research, as well as the willingness and ability to take corrective action, are some of the key components of an adaptive management program. The following steps can lead to a successful adaptive management program:

1. Defining the restoration goals and objectives, and how success will be measured.
2. Formulating a set of hypotheses that explain how a restoration action will achieve a desired result. Even if some or all the hypotheses are proven false, the information gained will ultimately help the restoration process.
3. Beginning the implementation of a restoration action, with monitoring designed to test the set of hypotheses. This is different than simply monitoring a list of resource parameters to test for possible trends. When monitoring is designed to test hypotheses, the causes and effects become better understood, and at a much faster pace.
4. If the desired outcome is not achieved through the restoration action, further research should be conducted to determine the underlying causes. Monitoring alone may not be sufficient to explain why a hypothesis has been disproven, nor to provide insights into what new or modified management actions may be required to attain the intended results.
5. Formulating a new set of hypotheses to explain how a new or modified restoration action will achieve the desired results.
6. Steps 3-5 are repeated until the restoration success is achieved. An adaptive management program will be successful if resource managers are willing and able to implement corrective actions. Resource managers should not be expected to blindly accept the recommendations for new or modified actions. However, objective presentations of the study results should help resource managers to make informed decisions.

With adaptive management, the uncertainty in the effectiveness of restoration approaches, due to the limited understanding of the involved mechanisms, is mitigated by learning by doing and adapting based on what is learned [3]. This approach has been extended to urban water systems and ecological restoration projects through Nature-Based Solutions (NBS), highlighting the role of long-term monitoring and flexible adaptation to environmental feedback [7, 8]. However, there is a lack of studies that evaluate biological responses using the Fish Biological Health Index (FBHI) under adaptive management frameworks over a multi-year period. Additionally, little is known about the spatial variability of the restoration outcomes within different reaches of a single river system.

The objective of this research is to establish a pre-(baseline) and post-construction monitoring adaptive management program at the Kamisaigo River Restoration Site. More specifically, the current research aims to verify project success by comparing restoration site indicator changes through the application of FBHI. The obtained results will contribute to the development of river monitoring and adaptive management. The novelty of this study lies in its focus on integrating multi-year FBHI data with adaptive management to evaluate ecological health at multiple river reaches. By comparing pre- and post-restoration biological indicators through FBHI, this study identifies spatial and temporal changes in ecological health across selected river reaches.

II. METHODOLOGY

The Kamisaigo River is one of the several rivers in Fukutsu City in the north of Fukuoka Prefecture, Japan, as shown in Figure 1. Fukutsu city currently encompasses an area of 52.70 km^2, which is situated in a highly structured agricultural landscape with both arable and grassland farming. The Kamisaigo River flows into the Saigo River and into the Tsushima Ocean on the west through the Fukutsu Area. Most of the river reaches were of the second order. The river had been altered over time due to the influence of improvement works for flood protection, which is a uniformly broad, monotonously running river, due to continuous river straightening since the 1970s.

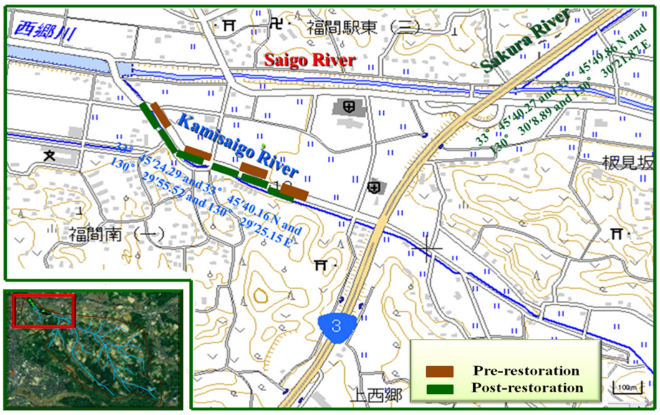

Fig. 1. Location map of the study reach of the Kamisaigo River.

Since 2009, the Kamisaigo River has undergone a restoration program aimed at enhancing habitat diversity, improving river aesthetics, and strengthening management practices. The selection of monitoring stations represented both pre- and post-restoration conditions. Stations 2–5 were designated as pre-restoration reaches, while Stations A–F represented post-restoration reaches. The first phase of the project began in 2009 at Station 3, where 1 m boulders were placed in the river, followed two years later by the installation of a breakwater. The second phase took place at Station 2, involving the construction of artificial riffles and, one year later, the placement of logs and native Japanese vegetation. A small weir was also installed at Station 4. Monitoring was conducted across 10 reaches between 2009 and 2012. The restoration measures varied among sites and included structural interventions such as boulders, riffles, logs, vegetation, and weirs. Biological monitoring was performed using electrofishing and evaluated through diversity metrics, including the Shannon and Simpson indices. The FBHI was also applied to assess ecological conditions based on fish community characteristics such as abundance, habitat preference, tolerance, and spawning behavior.

This study continues the Kamisaigo River post-restoration adaptive management evaluation program. It focuses on presenting the monitoring activities and findings from the third year of the post-restoration phase. The results are compared with data from Autumn 2009 (pre-restoration), Autumn 2011 (post-restoration), and Spring 2012 (third-year post-restoration). Baseline (pre-restoration) monitoring was conducted from October 26 to November 2, 2009. Following that, a comprehensive post-restoration monitoring program was implemented in three stages: the first in Spring (April 4 to May 19, 2011), the second in Summer (July 12 to August 19, 2011), and the third in Autumn (November 15 to 24, 2011). The third-year post-restoration monitoring took place from May 29 to June 18, 2012, during normal base-flow conditions. The monitoring activities included surveys of the water level and temperature, fish populations, physical environmental characteristics, geomorphological features, and physical biotope/flow ecological mapping. According to the fish surveys, the specimens collected through electrofishing were used to assess species richness and assemblage composition at each study site. All captured fish were measured and promptly returned to the water. Each species specimen was identified. To support the accuracy and repeatability of the surveys, habitat sketches, field notes, and photographs were also recorded. For data analysis, pre- and post-restoration conditions were described using consistent variables to enable a direct comparison. The FBHI was applied to compare ecological indicators across the years. Additionally, fish data were used to calculate the Shannon diversity index. The FBHI method presented in this study applies a quantitative, matrix-based approach to assess the temporal changes in restoration site indicators. The matrices are based on ecological traits and life-history characteristics of regional fish species [9, 10] and are currently used to monitor the success of the river restoration efforts within adaptive management frameworks. The FBHI incorporates 14 metrics that reflect ecological attributes of fish species, including habitat type (e.g., riffle, pool, muddy bottom), reproductive behavior (e.g., substrate spawning), tolerance to pollution, and flow preference. The FBHI was calculated using:

$$\mathrm{FBHI}_{ij} = 10 \times Nk_{ij} \,/\, N_{sj} \qquad (1)$$

where i is the station number (1–6), j is the metric number (1–14), N_{kij} is the number of species in metric j at the station i, and N_{sj} is the number of species in metric j at all stations combined.

The FBHI scores adequately represent the characteristics of river health and are used to determine which rivers (or segments of rivers) are successful post-restoration. The overall FBHI was calculated in three steps: (1) each FBHI_{ij} was calculated, (2) the mean of each metric was calculated, and (3) the FBHI_j of each metric was averaged to give the FBHI_{ij} of each station. Three common community diversity measures were also applied to analyze or compare the fish diversity among the six restored sites over time. The community measures included: (1) species richness or the number of species (S); (2) Shannon-Weaver index (H), a multifactor information index of community diversity incorporating both the number of species and their evenness; and (3) Simpson's Index ($1/D$), a multifactor dominance index differently assigning weight to common species. In all three indices, higher values represent greater diversity. The diversity indices were calculated using [11]:

$$Shanon - Wiener\ (H) = -\textstyle\sum_i^s = 1\ p_i L_n p_i \qquad (2)$$

$$Simpsons\ Diversity\ Index = \frac{N\,(N-1)}{\sum n\,(n-1)} \qquad (3)$$

where N is the total number of individuals (of all species) in the sample, n is the number of individuals of each species in the sample, p_i is the proportion of species relative to the total number of species, and S is the species richness. Sequential Bonferroni is a sensible, powerful, and easy-to-interpret way of addressing the multiple testing issues and has been advocated for ecological studies [12]. This procedure performs tests in order of increasing p-values, and conditional on having rejected tests with smaller p-values, an increasingly permissive threshold can be used while maintaining the FWER at the desired level (5%) and controlling the proportion of significant results that are in fact type I errors. The formula for doing this is:

$$\alpha_B = \frac{\alpha_{FWE}}{c} \qquad (4)$$

where α_B is the new alpha based on the Bonferroni test that should be used to evaluate the significance test, α_{FWE} is the family-wise error rate that is desired (often 0.05), and c is the number of comparisons. Hochberg's Sequential Method employs a "step-up" sequential procedure, which serves as a more powerful alternative to the traditional Bonferroni correction. In this approach, statistical tests are performed in a specific sequence determined by the outcomes of the preceding steps. Contrasts are ranked according to their p-values, from the smallest to the largest. Each subsequent step adjusts for the number of remaining tests rather than for all tests simultaneously. This method provides a robust and high-power alternative to other modified Bonferroni techniques, particularly when confidence intervals are not required.

III. RESULTS AND DISCUSSION

A 100 m reach of the Kamisaigo River, encompassing Stations B and C, was selected for adaptive management interventions, which included the addition of log structures. At Station E, a 50 m reach was enhanced through the installation of a breakwater structure. Furthermore, a 150 m reach spanning Stations B, C, and D was improved by adding riparian vegetation. Sampling of fish populations prior to the implementation of these adaptive management measures was conducted between May 29 and June 18, 2012. The analysis incorporated data from two earlier sampling periods: the pre-restoration survey conducted in Autumn 2009 (October 26-November 2) and the second-year post-restoration survey conducted in Autumn 2011 (November 15-24). Even though fish abundance significantly decreased during the research in the restored reaches, the fish species number increased. A clear difference in species numbers and species composition between the two reaches (Station B and Station C) is evident in Figure 2.

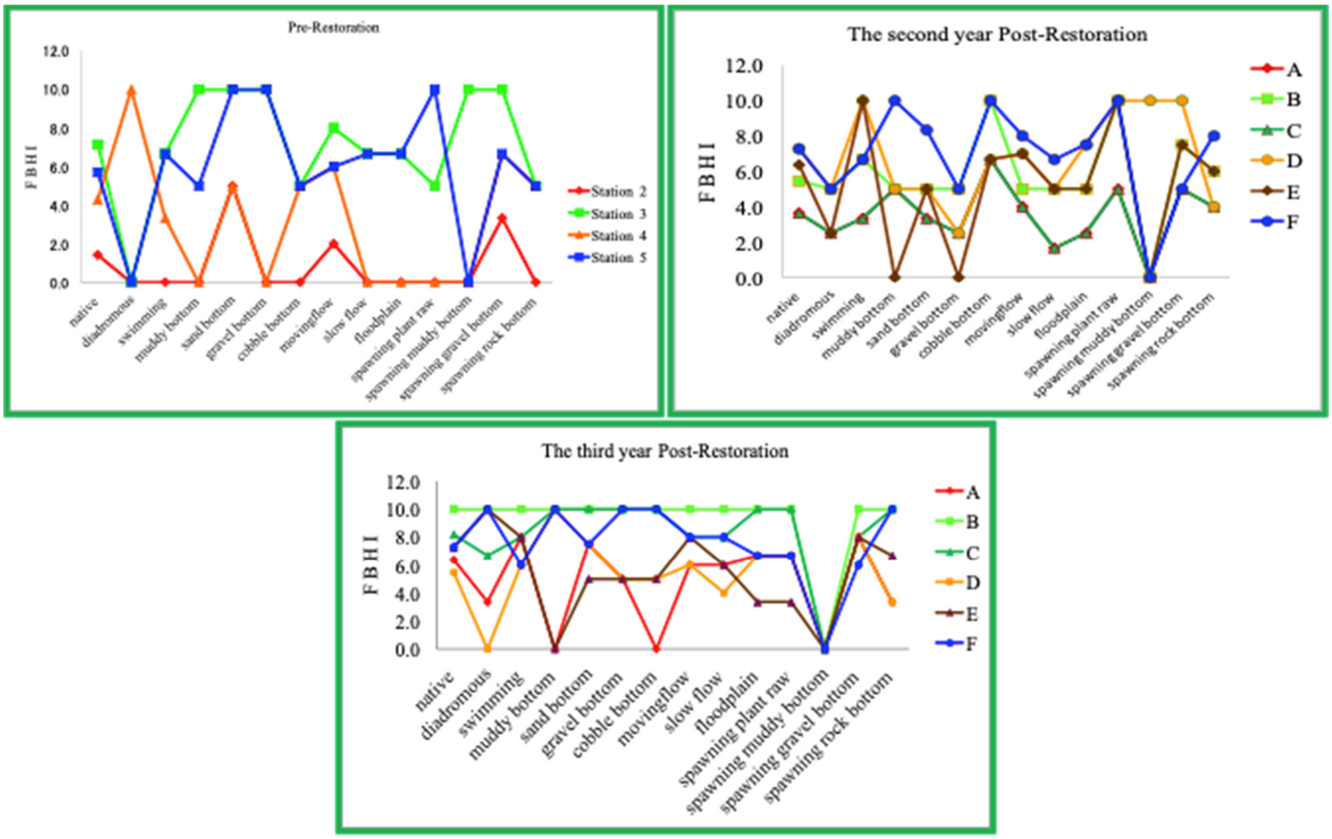

Fig. 2. Spatial changes in FBHI.

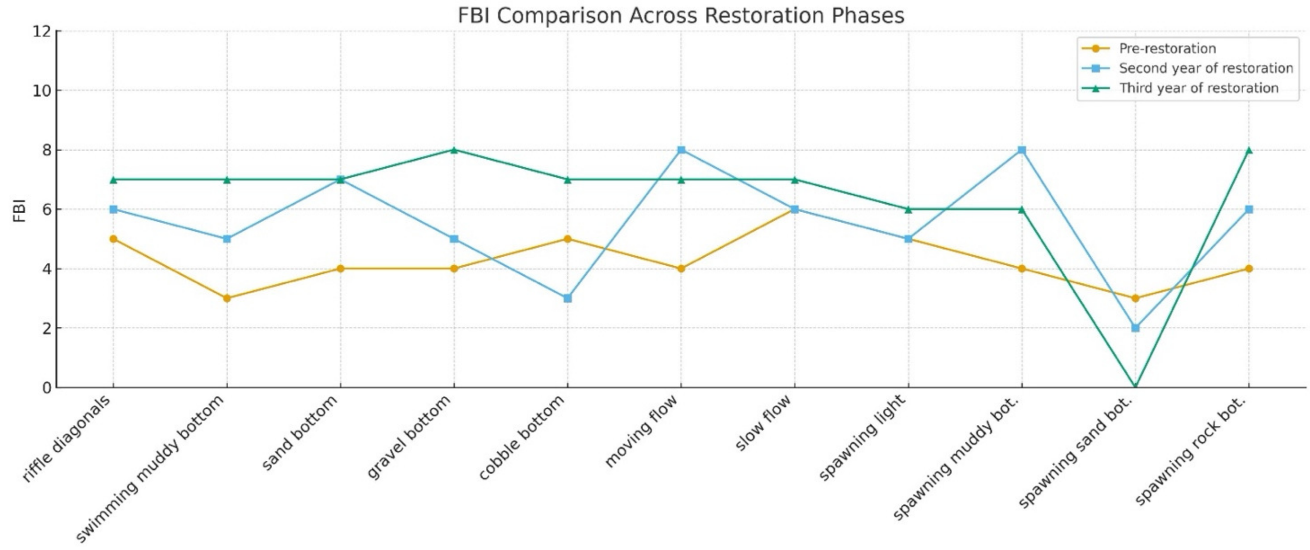

Fig. 3. Temporal changes in FBHI.

The three years of post-restoration monitoring revealed consistently high FBHI values, comparable to previous assessments, indicating that the river system is responding positively to the restoration efforts. In the third year, the FBHI showed the highest overall values among all indices, except for the metrics related to living in cobble-bottom habitats and spawning in plant substrates, both of which remained lower, with spawning in muddy-bottom habitats registering a value of zero, as depicted in Figure 3. Compared with pre-restoration conditions, the FBHI for spawning in muddy-bottom habitats decreased significantly. Nevertheless, the overall trend demonstrated that most FBHI metrics improved, reflecting positive ecological responses to restoration. These findings suggest that the implemented restoration model can effectively predict favorable ecological trends in the future, and that the constructed features of the Kamisaigo River Restoration Project currently support good to excellent biological health conditions.

Station B (artificially riffle and meandering, re-configuration of the reach by adding placing logs and native vegetation) had the highest FBHI measure scores. It was followed by Station C (meandering and reconfiguration of the reach by placing logs and native vegetation), which supported the highest biological health, and by Station F (small weir and meandering), whereas Station 2 (shallow) had the lowest scores. The surveys show that the meandering channel is sustaining a diverse fish community, whereas the Station C experienced a large drop in biological health in the second post-restoration year. However, despite Station D (meandering and 1 m sized rocks) was reconfigured with vegetation and Station E (meandering and 1 m sized rocks) was reconfigured with backwater, they could not exceed the average pre-restoration FBHI. This course will be a consideration for the next period of adaptive management.

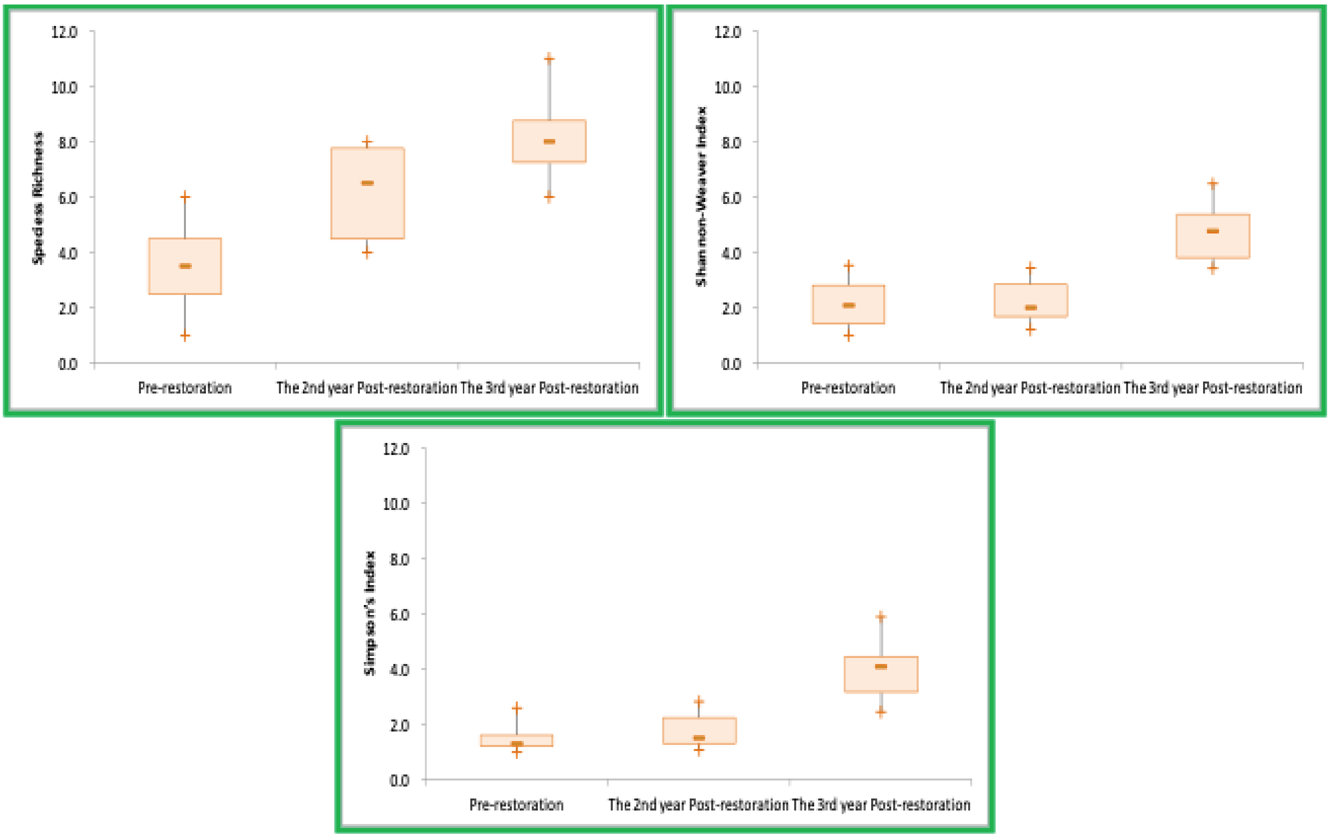

Fig. 4. Temporal changes of fish community diversity indices.

Although the river is a complex system, after the last monitoring survey, the pattern of each reach can be identified. The spatial and temporal changes of fish community diversity indices also supported the FBHI measurement results, as depicted in Figures 2-4. Species richness (*S*) ranged from 1 to 6 (mean = 3.5, SD = 2.08) pre-restoration, from 4 to 8 (mean = 6.17, SD = 1.83) in the second post-restoration year, and from 7 to 11 (mean = 8.17, SD = 1.72) in the third post-restoration year. Shannon–Weaver (*H*) ranged from 1 to 3.52 (mean = 2.17, SD = 1.10) pre-restoration, from 1.22 to 3.43 (mean = 2.23, SD = 1.83) in the second post-restoration year, and from 3.42 to 6.48 (mean = 4.75, SD = 1.17) in the third post-restoration year. In the third year after restoration, the Shannon index reached its highest value of 6.48 at Station C, followed by 5.51 at Station B, indicating high community diversity across all stations. In contrast, the pre-restoration and second-year post-restoration results reflected conditions ranging from moderately clean to clean water. According to [13], a Shannon index (*H*) value greater than 3 signifies clean water, the values between 1.00 and 3.00 represent moderately clean water, and the values below 1 indicate heavily polluted water. Simpson's metric ($1/D$) ranged from 1 to 2.59 (mean = 1.55, SD = 0.71) pre-restoration, from 1.08 to 2.82 (mean = 1.78, SD = 0.71) in the second post-restoration year, and from 2.45 to 5.89 (mean = 4.00, SD = 1.22) in the third post-restoration year. It is also clear that diversity fluctuates in a similar pattern for all three time variables, and all fish community diversity indices increased grossly in the third post-restoration year.

The following FBHI index comparisons were also checked with a priori contrasts when a significant treatment effect was detected using sequential Bonferroni methods and t-test: 1) pre-restoration versus the second post-restoration year, 2) pre-restoration versus the third post-restoration year, and 3) second versus third post-restoration year. After correction, only one mean difference value remained significant (r_{13} = 2.478 by P-value = 0.002 < Bonferroni corrected P-value = 0.05/3=0.016667), with a 95% confidence interval. This sequential Bonferroni analysis has shown that there is a significant difference between pre-restoration versus the third post-restoration year treatment means and t-test results (P-value = 0.000 sign 2-tailed < α = 0.05). Moreover, there is also an important difference between the second and the third year post-restoration treatment means (P-value = 0.007, sign 2-tailed < α = 0.05).

The pattern at each station was examined separately, because several species were only abundant enough to be included in the statistical analysis for one reach/station, and then multiple comparisons were made with the same sample set, as illustrated in Table I. Within no meandering, no consistent pattern of differences was observed in Station A according to both sequential Bonferroni and t-test analyses. The transitory, the metric of the total index in Stations B and C, which were both re-configured by logs/woody debris and native vegetation, were significantly higher, except for the metric of spawning in the muddy bottom of the third year post-restoration compared with pre-restoration and the second year post-restoration. This was supported by both the sequential Bonferroni and t-test analyses, where all p-values were equal to zero. Reconfiguring by logs/woody debris allowed the presence of pools. The presence of deep pools is a critical component of a high-quality physical habitat for fish, as it provides shelter and cool temperatures during the summer months [14]. Woody debris affects the morphology of a stream by creating complex stream characteristics, including riffles, pools, scour holes, overhead, and submerged cover [15]. The retention or replacement of large woody debris in chalk streams can have a significant benefit in creating a habitat. Large woody debris causes local changes in water speed and direction, cleaning the gravel bed in high flow areas, depositing fine sediment in areas of low velocity. Authors in [16] revealed that introducing Structural Woody Habitats (SWHs) may be a useful tool for rehabilitating rivers, especially those with little or no riparian vegetation. Authors in [17] stated that spatial and temporal changes in fish assemblage structure are anticipated because of the rehabilitation measures, consisting of increased abundance of those fish species with a known dependence on woody debris and increased species richness.

Unfortunately, Stations D and A had no consistent pattern of differences according to the sequential Bonferroni. However, there is a significant difference through the t-test between the pre-restoration versus the second post-restoration year treatment means (P-value = 0.007, sign 2-tailed < α = 0.05).

TABLE I. KAMISAIGO RIVER STATISTICAL ANALYSIS SUMMARY. THE HIGHLIGHTED STATIONS HAVE CHARACTERISTICS CONSISTENT WITH THE VALIDATED FBHI DATA SET

Station	Sequential Bonferroni		T - Test
	P-Value	Corrected P-Value	
A			
P1 – P2	1	0.025	0.131
P1 – P3	1	0.05	0.477
P2 – P3	0.369	0.017	0.191
B			
P1 – P2	0.389	0.05	0.078
P1 – P3	0.000	0.017	0.000
P2 – P3	0.000	0.025	0.000
C			
P1 – P2	0.907	0.05	0.131
P1 – P3	0.000	0.017	0.000
P2 –P3	0.000	0.025	0.000
D			
P1 – P2	0.021	0.0167	0.007
P1 – P3	0.828	0.05	0.134
P2 – P3	0.271	0.025	0.140
E			
P1 – P2	1.000	0.025	0.391
P1 – P3	0.871	0.017	0.185
P2 – P3	1.000	0.05	0.718
F			
P1 – P2	0.013	0.025	0.003
P1 – P3	0.002	0.017	0.001
P2 – P3	1.000	0.05	0.314

Likewise, Station E, although reconfigured by backwater to achieve its full ecological potential, did not present a consistent pattern of differences according to the sequential Bonferroni and t-test analyses. The metrics of muddy bottom and spawning muddy bottom provide a zero value based on the FBHI model. In contrast, in Station F the results were very encouraging. Both the sequential Bonferroni and paired t-test analyses supported the results ($r_{13} = -3.290$ by P-value = 0.002 < Bonferroni corrected P-value = 0.05/3=0.016667 and $r_{12} = -2.668$ by P-value = 0.013 < Bonferroni corrected P-value = 0.05/2=0.025) and (P-value = 0.003 and 0.001 sign 2-tailed < α = 0.05).

IV. CONCLUSIONS

Evidence indicates that the river is functioning well after the restoration works. Based on biological health assessments, Stations B, C, and F have been identified as supporting the best-adapted species in the area. The management needs have been addressed, and an adaptive management plan is required to develop Stations A, D, and E from the current good state to one of excellent biodiversity.

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