Establishment of the comprehensive river environment conservation system in collaboration with river stakeholders on the Tenryu River

Constitution du système global de préservation de l'environnement fluvial en collaboration avec les acteurs fluviaux sur la rivière Tenryu

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Abstract. The sedimentation, turbid water and water quality are typical environmental issues for dams and reservoirs which have impact on the reservoir and downstream of dams. These impacts are influenced from the upstream of a dam, and influence to the downstream. Therefore, a more integrated environmental management approach and consideration have been required for the whole river system. The Tenryu River in Japan flows through the erodible area near the Median Tectonic Line on Honshu, the main island of Japan, and continuously carries a lot of sediment during floods. The "Tenryu River Natural Resources Rebirth Promotion Committee" was established in 2012. The purpose of the committee is to restore fish resources and improve the river environment. The feature of the liaison committee is that it is composed of the Tenryu River fisheries association, academic experts, and dam owner and exchanges knowledge and technology information in spite of each interest. The current activities are related to the theme of "attached algae/environmental DNA survey", "turbid water measures in reservoir/spawning bed construction technique at downstream," and "information dissemination". In this paper, the activities of the comprehensive reservoir and river environment conservation system in collaboration with river stakeholders are introduced and described, including future prospects.

Résumé. La sédimentation, turbidité et qualité de l'eau sont les problèmes environnementaux typiques des barrages et réservoirs ayant un impact sur ces derniers, mais aussi à l'aval des barrages. Ces impacts naissent en amont

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d'un barrage et impactent l'aval. Une approche et une considération de la gestion environnementale plus intégrée furent donc nécessaires pour tout le système fluvial. La rivière Tenryu, au Japon, traverse la zone érodable de la Ligne tectonique médiane sur Honshu, l'île principale japonaise, et transporte continuellement beaucoup de sédiments lors des crues. Le « Comité de promotion de régénération des ressources naturelles de la rivière Tenryu » a été créé en 2012. L'objectif est de restaurer les ressources halieutiques et d'améliorer l'environnement fluvial. Le comité de liaison est formé par l'association des pêcheries de la rivière Tenryu, des experts universitaires et propriétaire du barrage échangeant connaissances et informations technologiques malgré des centres d'intérêt divers. Les activités actuelles incluent les thèmes « Étude de l'ADN environnementale/algues », « Mesures de turbidité dans la technique de construction des réservoirs/frayères en aval » et « Diffusion d'information ». Les activités du système global de préservation des réservoirs/environnement fluvial, en collaboration avec les acteurs fluviaux, sont décrites ici, avec les perspectives futures.

1 Introduction

The Tenryu River's tributaries in Japan, which have their sources in the Tenryu River Central Alps and the South Alps, flow on brittle rocks near the Median Tectonic Line, and continually wash away much earth and soil every time flooding occurs. Sedimentation has progressed also at the Sakuma Dam. While its total water storage capacity was initially 327 million m^3, but the sedimentation rate has now reached 37% (result of a 2020 survey) of the capacity. In addition, not only sedimentation, but also turbidity elongation and environmental changes, for example in water quality, also have long been an environmental change problem due to dams.

These environmental changes also affect the life and distribution of aquatic organisms in rivers, and may lead to change in local livings such as those of inland water fisheries. Such impacts would stretch to extensive areas including the Sakuma Dam, Akiha Dam and Funagira Dam. Since there are many river stakeholders who are relevant to environmental measures, it would take a long time to gain an understanding of such measures, and achieve coordination and implementation of the measures.

In Japan, environmental rights to rivers are not clearly specified, and only fisheries cooperative associations are entitled to human intervention for rivers. Therefore, coordination with a fisheries cooperative association would involve difficulty. Therefore, a more integrated environmental management approach and consideration have been required for the whole river system.

In this paper, the activities of the comprehensive reservoir and river environment conservation system in collaboration with river stakeholders are introduced and described, including future prospects.

2 The Tenryu River and Natural Resources Rebirth Promotion Committee

2.1 Outline of the Tenryu River

The Tenryu River is a Class A river with a catchment area of 5,094 km2 and a total main channel length of 213 km that has its source in Lake Suwa, flows in mountainous terrains of

Oku-mikawa and Hokuen, and empties into the Sea of Enshu (Pacific Ocean) via the Enshu Plain. On the Tenryu River, a large number of dams have been constructed with the aims of flood control, irrigation and power generation.

Among them, the Sakuma Dam is the largest in size and especially important. The Sakuma Dam is a gravity dam with a crest length of 294 m and height of 156 m that was constructed in the middle reach of the Tenryu River. The power it generates accounts for one third of the water power resources of the Tenryu River, and represents one of the largest powers generated in Japan (approximately 1.5 billion kWh/year). Part of its impoundment is directly used for agricultural industrial water, supply and sewerage systems, in addition to being used for power generation at the Akiha and Funagira Dams downstream of it and for other irrigation purposes (Figure 1).

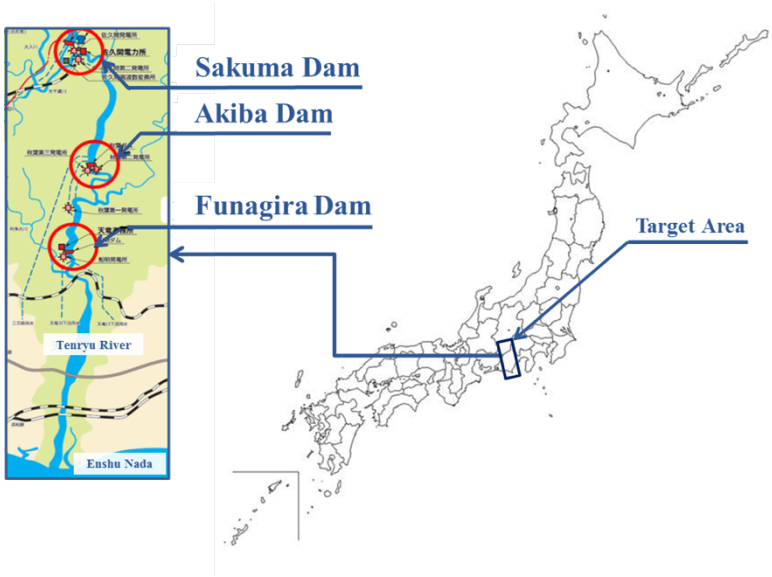

Fig. 1. Tenryu River system and target area.

2.2 Natural Resources Rebirth Promotion Committee

Against such a background, the Tenryu River Natural Resources Rebirth Promotion Committee was established in 2012 after a preparatory period of three yeras [1]. The purposes of the Committee are to preserve and regenerate the river environment of the Tenryu River and create a new environment for the river. In particular, the prime purpose is to recover fish resources (Ayu [sweetfish]) and improve the river environment (Figure 2). The Committee is characterized in that it consists of the Tenryu River fisheries association, academic experts and dam owner. Now, national and prefectural river administrators have joined the Committee as advisors. The Committee is also characterized in that it pursues information exchange for knowledge and technologies on the river environment and promotes technological development and collaboration across different standpoints in such a manner.

Fig. 2. The Tenryu River Natural Resources Rebirth Promotion Committee.

3 A survey on the environmental characteristics and ecology of the river

3.1 Attached algae and importance of an ecological survey

Ayu, which is a major subject of the Committee's activities, feeds on the primary producer (attached algae), and is susceptible to the floristic composition and biomass of attached algae. A more important factor is the production rate. The production rate of attached algae is substantially subject to the presence or absence of a stream, and water temperature and turbidity. In the river environment, the conditions of algae attached to the river-bed material also change with a physical environmental change such as the travelling of the river-bed material and the change in grain size (Figure 3). The recovery of the Ayu catches would require improvement of the environment including such ecology. A survey of the ecology of attached algae and Ayu would serve as a major clue to grasping and assessing the state of change in the river environment and productivity. To regenerate the Tenryu River, it will be important to collect and store information on the Tenryu River and encourage the local people concerned to better understand the Tenryu River. It will be effective to implement feasible measures in light of these [2, 3].

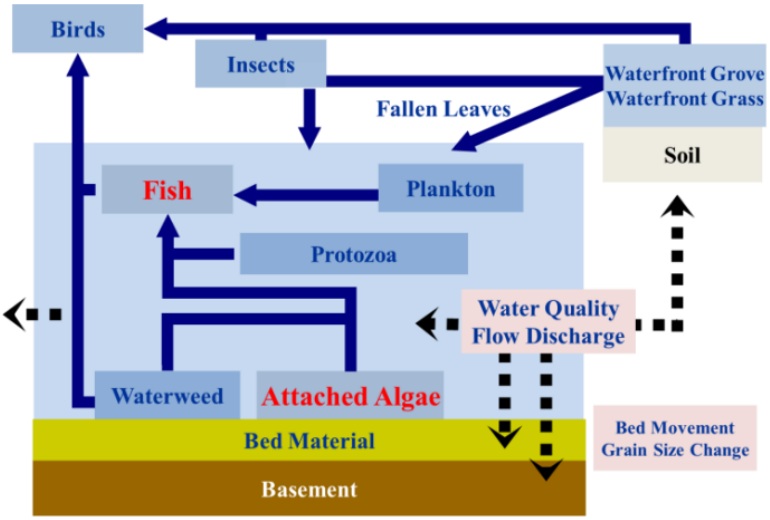

Fig. 3. Structure of ecosystem in river system.

3.2 Ecological evaluation using environmental DNA

It will be impossible to improve the whole environment of the Tenryu River, which is a large-scale river. Therefore, it is necessary to identify a section that Ayu heavily uses for each developing stage, and implement an environmental improvement measure for that section. A water sampling survey for environmental Deoxyribonucleic acid (eDNA, or environmental DNA, Figure 4) was conducted at 9 spots in a section, extending approximately 47 km upstream from the river mouth during the colonization period (main active period) of Ayu in 2019, at 11 spots during the spawning, hatching and downstream-migration period in 2017 to 2019, and at 6 spots during the marine water life period in 2018 to 2019. The eDNA concentration of Ayu in the sampled river water was measured using the quantitative Polymerase chain reaction Method (PCR Method).

The result showed a tendency of similarity between the bite mark (Figure 4) cover degree examined on that day for the level of the measurement during the colonization period, and the main spawning section estimated from the result of an examination of larval Ayu migrating downstream conducted for 13 years from 2006 to 2018 for the level of the measurement during the spawning, hatching and downstream-migration periods (Figure 5). Then values of bite mark cover degree show relatively high at the downstream 10 km and 15 km sections, and they show low at 5 km and at 25 km section. The eDNA concentration also shows high value at 10 km and 15 km sections, and they show low at 5 km section. The value of bite mark cover degree was high and eDNA concentration was low at 5 km sections. It is conceivable that the value of bite mark over time was remained. It was also found in another measurement that there was a tendency for a higher eDNA concentration at river mouth in the marine water life period of Ayu. These results are suggesting that it reflected the presence of larval Ayu. Judging from this, it was considered that the level of the eDNA concentration reflected the Ayu utilization in the river [4].

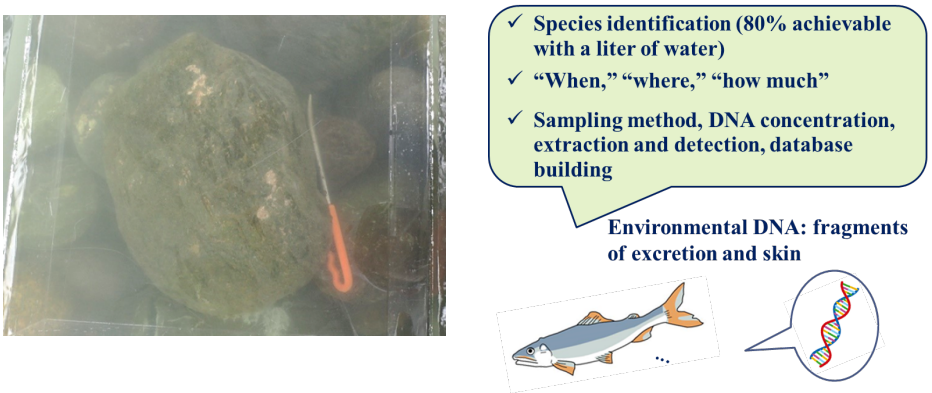

Fig. 4. Bite marks of Ayu in Tenryu River (left), and concept of eDNA (right).

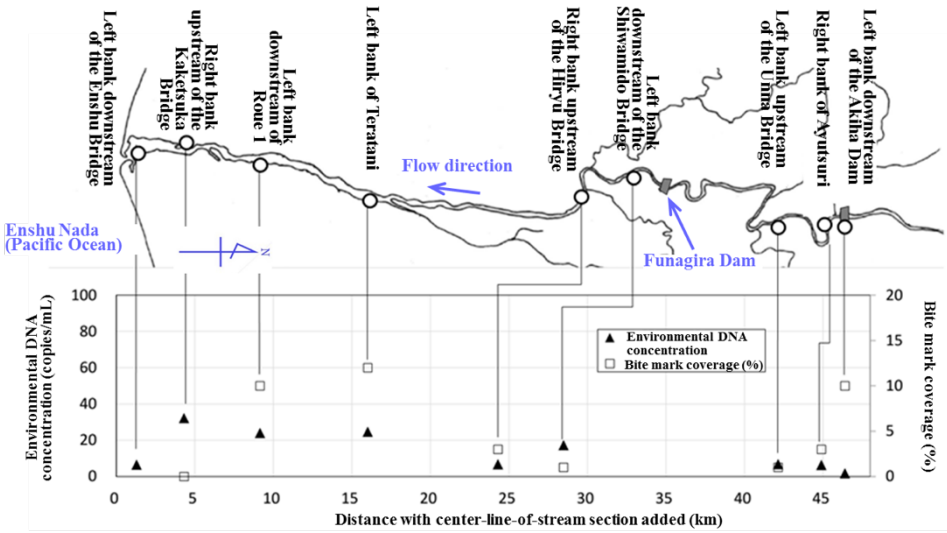

Fig. 5. Result of comparing the eDNA concentration and the bite mark coverage (September 20, 2019).

4 Preservation measure testing in cooperation with local people concerned

4.1 Environmental improvement through river-bed tilling

River-bed tilling is a technique for restoring an ecological environment friendly to Ayu by washing the silt content (fine sand) and filamentous green algae attached to gravels of the reverbed to improve the condition so that diatoms and blue algae, which serve as feed for Ayu, are renewed. In the river-bed tilling method, a bulldozer equipped with a ripper reciprocates to stir gravels of the river-bed (Figure 6). This method has three effects: a)

peeling off algae on the gravel surface, b) peeling off algae by stirring/rubbing gravels, and c) exposing the gravels' bottoms by flipping them over.

Fig. 6. State of river-bed tilling using a bulldozer's ripper on May 24, 2019.

The river bed tilling test was conducted in a natural sandbank located in the middle of a river channel downstream of the Akiha Dam in May 24, 2019 (Figure 7). River-bed tilling was performed in an experiment section (with total length of 200 m), that was set up in a river channel on the left bank, and the changes in the amount of attached algae [5] and in the state of sediment on the river-bed before and after the tilling were examined. Using the river channel on the right bank as a control section, a survey in the same items as the experiment section was conducted. The rate of decline in the amount of attached algae between before and after the tilling was larger in the experiment section, indicating that the washing effect of river-bed tilling was observed (Figure 8). In addition, in the experiment section, new covering of attached algae and eating by Ayu were observed. Further, with the rate of green algae recovery being small, the tilling's effect of delaying the exuberance of green algae after being stirred was also observed. In the meantime, although the river-bed softness increased after tilling in both the experiment and control sections, the improvement effect was not lasting (Figure 8).

For this technique, using a potential coping technique in a place where it would be effective, concerned people cooperatively conducted a site test based on the environmental characteristics in 2019. Since many anglers entered the river after the tilling work, it is considered that the ecological environment was improved, though only temporarily. River-bed tilling is effective as a method for improving a river-bed to make it suitable for the development of Ayu.

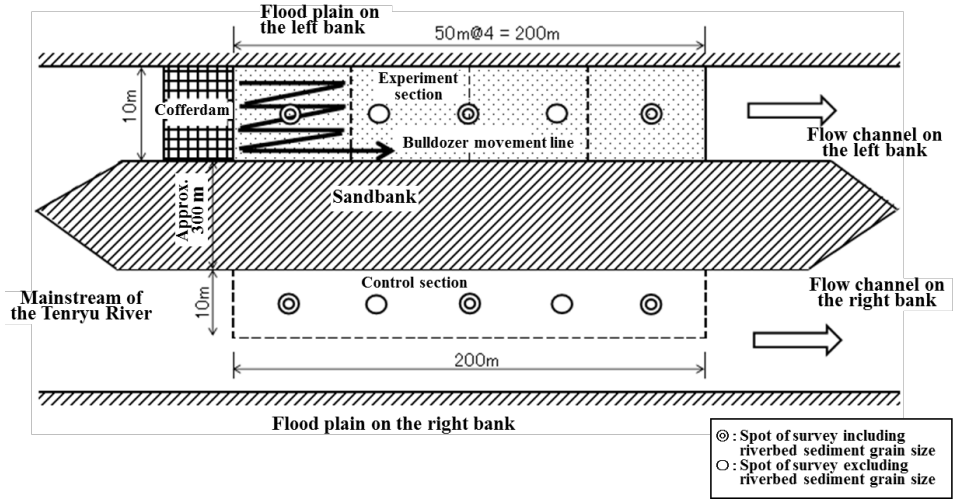

Fig. 7. Conceptual drawing of the work area for the river-bed tilling test in 2019.

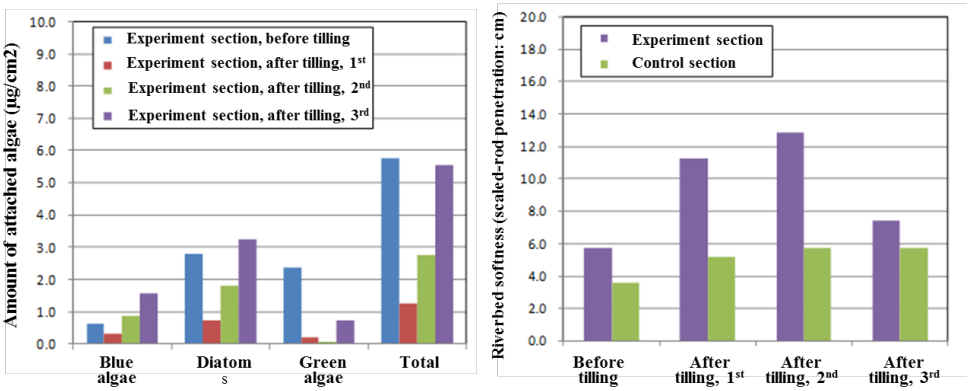

Fig. 8. Temporal change of the amount of attached algae (left,) and the river-bed softness (right) in the experiment section (the examinations were before tilling, after 4 days later as 1st, after 12 days later as 2st, and after 19 days later as 3rd.

4.2 Construction technique for an artificial spawning bed

According to a multiple-regression analysis on ecological data of the Tenryu River during 26 years, the secular change in the Ayu catches obviously showed a possible correlation with the amount of stocked Ayu. The Ayu resources are artificially influenced by the stocks Ayu. In addition, according to a principal component analysis, catch changes are highly related to Dissolved oxygen (DO) and Biochemical oxygen demand (BOD), and the larger the amount of stocked Ayu in a year, the larger the number of relations becomes [1, 2]. High value of DO suggests to accelerate photosynthesis and activity of attached algae. And also, low turbidity relates photosynthesis and activity of attached algae. Production rate of attached

algae is important as feeds for Ayu. The Committee has especially considered to release and increase not only hatchery larva Ayu, but also larva Ayu by wild spawner Ayu. Therefore, it is very important to increase the amount of spawned eggs by wild spawer for the recovery of Ayu resources.

This technique is intended to artificially construct an Ayu spawning bed in a sandbank located in the potential Ayu utilization section. In the site test, the state of the actual spawning was surveyed, and an evaluation of the increase in the natural Ayu resources was attempted [6]. For the spawning bed, an open channel is built by excavation in a manner to travel through the sand bank from the upstream end to the downstream end on the border nearest to the centre line of stream of the sand bank, and gravels with a grain size suitable for the spawning of Ayu are laid on the channel bed (Figure 9). In this spawning bed approach, the spawning bed is left in the site after the spawning of Ayu in order to let it naturally change. In 2017 and 2018, the spawning bed was unfortunately washed out due to inundation occurring after the construction and no evaluation was conducted. In 2019, the test was also suspended due to a lengthy flood during the spawning period. It is planned to continue the test in 2020 and in the future in order to make the technique practical. The channel will be designed more durable and stable, and be set in better timing by using weather forecast.

Fig. 9. Diagonal and vertical aerial shots taken immediately after the completion of construction on November 1, 2018 (top and lower left); Throwing of gravel and gravel thrown in the channel (top and lower right).

5 Preservation measures at dam reservoir and other activities

5.1 Countermeasure technique against reservoir turbidity

The Sakuma Dam is large in scale therefore its water quality affects downstream water quality. Not only does it face the problem of blocking with earth and sand inflow, but also turbidity elongation due to fine earth and sand has occurred. As shown in the previous section 4.2 turbidity elongation influences the amount of stocked Ayu. Some preservation measures for turbidity elongation at Sakuma Dam is desired.

The annual turnover rate of the Sakuma Dam is 20 or more, and therefore, the dam is classified as mixed type. However, since the impounding length is approximately 30 km, which is long, the water temperature at the reservoir surface rises in the summer. Therefore, thermal stratification occurs, and high-density turbid water flow is substantially affected by thermal stratification. Installing a turbid water fence is one of the turbid water countermeasures based on flow control using thermal stratification. As a result of various studies, a turbid water fence was recently installed at a spot 500 m upstream of the dam, and currently an operational test is being conducted (Figure 10). This technique has effects of storing clean water upstream of the turbid water fence in case of flooding (Figure 11), and demonstrating its function for promptly discharging turbid water without spreading the incoming turbid water across the whole reservoir (Figure 12).

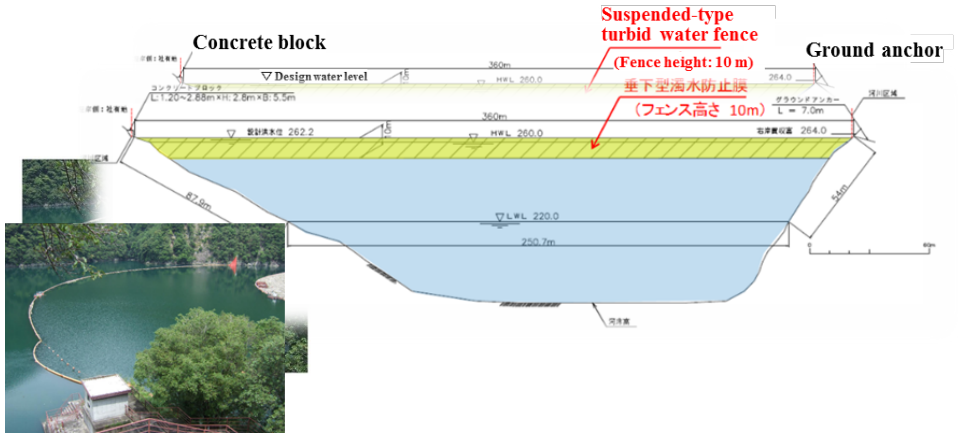

Fig. 10. State of turbid water fence installed in the Sakuma Dam at cross section No.2.

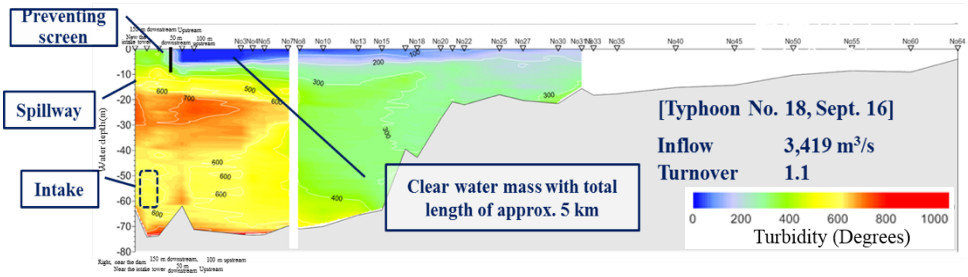

Fig. 11. Iso-turbidity diagram of storing clean water upstream of the turbid water fence after Typhoon No.18 flooding in the Sakuma Dam on September 16, 2013.

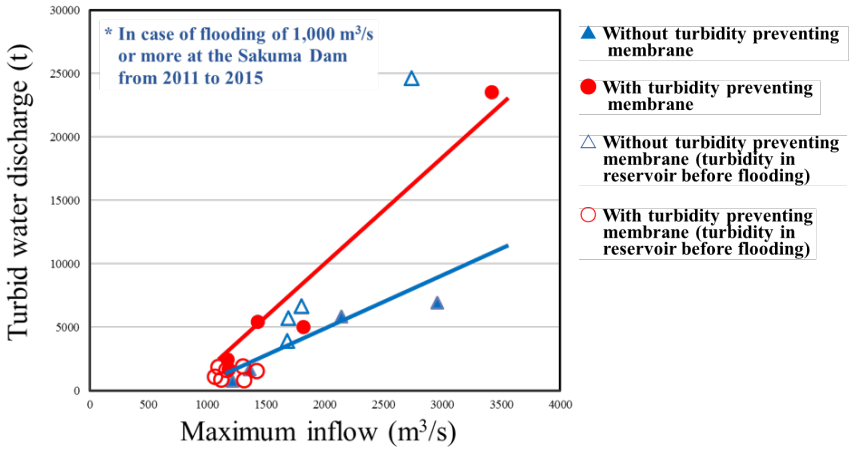

Fig. 12. Turbid water discharge from Sakuma Dam from 2011 to 2015.

There is another turbid water countermeasure, which uses a string-shaped filter media (Figure 13). This is a woven filter media having high performance in retaining attached matter and in accelerating sedimentation. It is designed to be installed with a vertical length of approximately 10 m, and resembles seaweed. It is planned to finally install multiple units of this filter media densely in the transverse direction of the reservoir. This has a mechanism of attaching turbid matter in floc to its surface, and then letting the attached matter naturally peel off and settle [7]. Unlike a turbid water fence, its flow resistance is small, and is unlikely to serve as an obstacle in the event of flooding. Its effect has so far been confirmed through application tests with dam reservoirs (Figure 14).

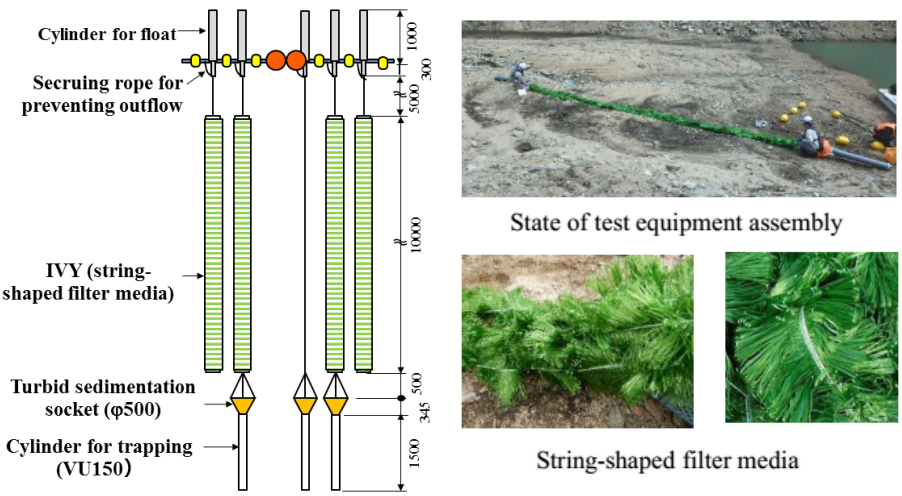

Fig. 13. String-shaped filter media with high performance in retaining attached matter, in accelerating sedimentation, and with 10m vertical length, and like seaweed.

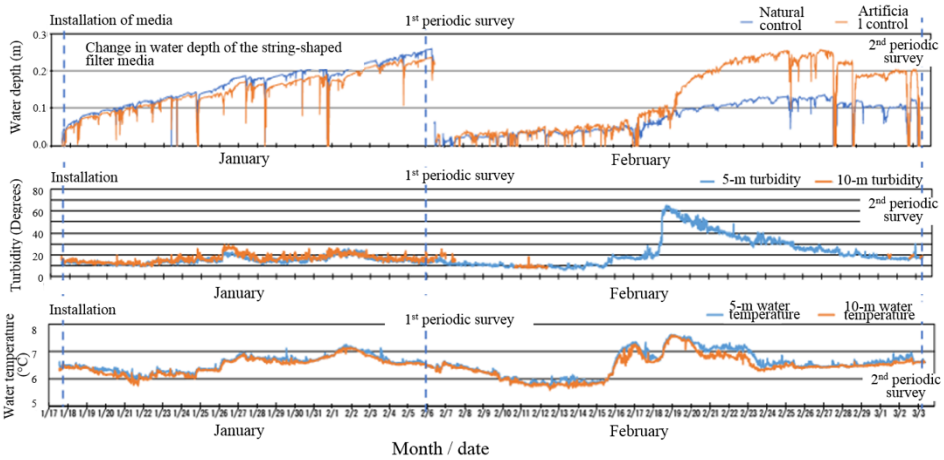

Fig. 14. Result of continuous observation on depth of string-shaped filter media, turbid water and water temperature in2019 (effects shown as amount of change in water depth of the media).

5.2 Creation of a simplified prediction model

Measures to improve the ecology of Ayu need to be convincing to all major river stakeholders consisting of the local community, the river administrator and academic experts. To achieve such an objective, we surveyed the development stages of Ayu and utilization sections for each season [8] with the downstream basin of the Tenryu River taken as an example, and created a support model (AYU48) that presents options for improving the ecology of Ayu, which river stakeholders must consider on a top-priority basis for each season (Figure 15 and Figure16). The idea is to estimate improvements in the ecology of Ayu, based on data on the physical environment of this model [9]. This tool will help river stakeholders to easily make a decision. The model is at a stage of prototype, and its performance is being verified.

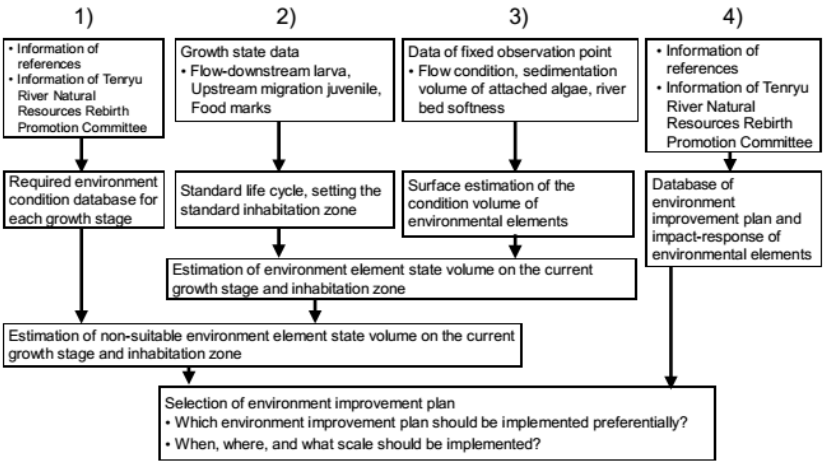

Fig. 15. An outline flow of the improvement plan selection support program for Ayu inhabitation environment.

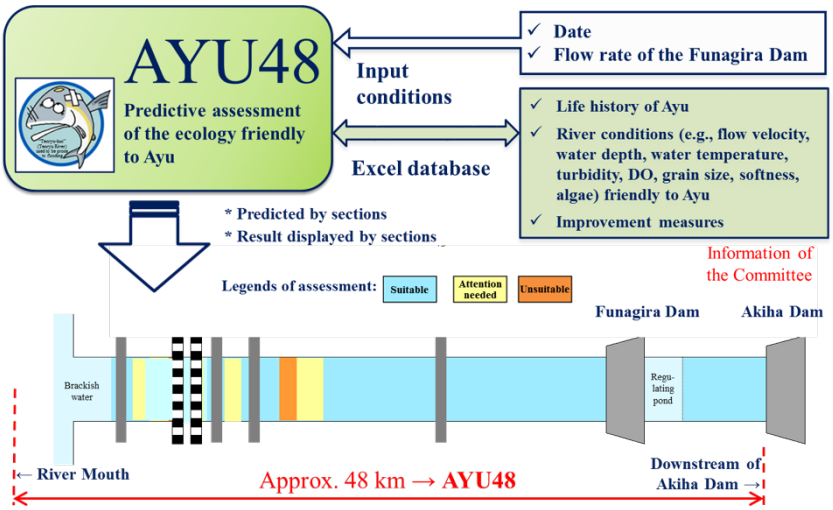

Fig. 16. Conceptual diagram of the improvement plan selection support program for Ayu inhabitation environment (AYU48).

5.3 Prospect of information dissemination and activities

To ensure continual recovery of the Ayu catches and improvement of the river environment, participation not only of the Tenryu River fisheries association and dam owner to use of the river water, but also of local people concerned and general river stakeholders will be essential. In particular, it is considered that the consciousness by the local people concerned of the environment of the Tenryu River in their everyday life is the most important factor for achieving sustainable regeneration. Therefore, the Rebirth Promotion Committee understands the importance of disseminating information on the state of its activities, and continually disseminates information and techniques on environmental preservation for the Tenryu River, as well as other information, to various people concerned via its website (in Japanese only) (http://www.tenryugawa.jp).

In addition, the Committee holds symposia and events. In the future, understanding by and cooperation with local people concerned will be important, and it will be important to pursue its activities while taking care to prevent the activities from being conducted by limited people concerned and with a limited value. In the future, the Committee intends to provide the opportunity for the local people concerned and the river administrator to participate more actively in decision-making for environmental preservation, and discuss matters related to the river such as irrigation and flood control.

6 Conclusions

This paper reports a case example of efforts for comprehensive environmental preservation, in which such efforts have been conducted for the Tenryu River in cooperation with river stakeholders, as well as future prospects. The results that have been gained are as follows:

(1) In terms of systematic efforts aimed at preserving and regenerating the river environment, and creating a new river environment, it is important for river stakeholders to exchange information such as findings and technologies concerning the river environment across different standpoints, and develop required techniques in cooperation with each other, and such efforts are effective for environmental preservation activities involving the whole watershed.
(2) A survey of the ecology of attached algae and Ayu would serve as a major clue to grasping and assessing the state of change in the river environment and productivity. In the case of large-scale rivers, it is difficult to identify individuals for evaluating the productivity. However, with an eDNA analysis, it will be possible to estimate the high-utilization area.
(3) For comprehensive environmental preservation management of dams and rivers, understanding and cooperation of the local people concerned will be essential. River-bed tilling is a technique that enables concerned people to lead to developing a coping technique in cooperation with each other, as a potential coping technique in a place where it would be effective, and is very important.
(4) The Committee expects that a technique of artificially constructing a spawning bed for wild spawer Ayu will be effective, in increasing the resources in the high-utilization section for Ayu. In the future, the Committee plans to continue tests aimed at establishing as a practical technique.
(5) With a turbid-water fence that uses density stratification, it will be possible to store clean water in a reservoir and promptly discharge turbid water. A measure with a string-shaped filter media is also considered as effective by directly attaching and holding fine earth and sand and enhancing sedimentation accelerating performance.
(6) Disseminating information through its website on the state of activities concerning environmental preservation and on coping measures is important for continually conducting the Committee's activities.

The environmental impact of a dam reservoir is an inevitable problem that starts with the establishment of the dam. In addition, this environmental impact involves extensive areas including those upstream and downstream of the dam reservoir. The Committee intend to continue our systematic efforts in the future for the Tenryu River in cooperation with the local people concerned.

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