HYDRO-GEOMORPHOLOGICAL FORMATION PROCESSES OF SPAWNING HABITATS FOR AYU FISH REQUIRED UNDER TURBID CONDITIONS BY DAM IMPACTS IN THE TENRYU RIVER

MAKOTO HYODO
IDEA Consultants, Inc., Osaka, Japan, hyodo@ideacon.co.jp

SHINJI TAKAHASHI
Tohoku University, Sendai, Japan, shinji.takahashi.a4@tohoku.ac.jp

HIROMI YAMASAKI
Kyoto University, Uji, Japan, yamasaki.hiromi.58c@st.kyoto-u.ac.jp

YASUHIRO TAKEMON
Kyoto University, Uji, Japan, takemon.yasuhiro.5e@kyoto-u.ac.jp

TETSUYA SUMI
Kyoto University, Uji, Japan, sumi.tetsuya.2s@kyoto-u.ac.jp

ABSTRACT

Plecoglossus altivelis altivelis (Ayu [in Japanese]) is anadromous fish well-known and important fishery resources in Japan. They spawn on the loose gravel-riverbed in riffles, like Salmon and Trout, in November to December in Japan. Although the Tenryu River was known for fairly high density of Ayu among Japanese fishermen, the fish has been reduced in population due to gravel mining and dam construction upper stream leading to reduced sediment supply, riverbed degradation and turbid flow discharge, negatively affecting environmental conditions of the spawning redds. Objective of this study is to analyze relationship between hydro-geomorphological formation processes and spawning sites for Ayu in the Tenryu River under the altered flow and sediment regimes and turbid water conditions. Firstly, we conducted a series of surveys on spawning sites in 2018 and 2019. We could not find any spawning redds in riffles of the main channels, but found in riffles of the spring channels in the gravel bars. Secondly, we analyzed relationship between changing patterns of riverbed by floods and distribution patterns of spawning sites, using aerial photos and satellite images. It was revealed that old channels deposited during floods play an important role in creation of the spring channels gathering the up-welling water from hyporheic zones in the gravel bars. Thirdly, we measured the turbidity in main channels and the secondary channels including the spawning redds of Ayu. Results showed that turbidity was distinctively lower at the spawning sites than the main channels. Based on these results, we discussed on characteristics of the river channel configuration maximizing spawning success of Ayu and on the geomorphological processes for creating the channel configuration.

Keywords: Spawning redds, hydro-geomorphological process, river channel configuration, up-welling zone, turbid water

1. INTRODUCTION

Plecoglossus altivelis altivelis (Ayu) is anadromous fish well-known and important fishery resources in Japan. They stay around river mouth and shoreline area in a juvenile period, move up to a middle reach of rivers to grow up, and spawn on the riffles.

Previous studies showed that suitable spawning redds are riffles (Ishida, 1961), loose gravel riverbed (Ishida, 1962 and 1964), sediment particle size composed of sands and small gravels, etc. (Ishida, 1961), similar to those of Salmon and Trout in Europe and USA, for example, in the Columbia River (Geist and Dauble, 1998, and Geist, 2000), Merced River (Utz et al, 2013) and Trinity River (Brown and Pasternack, 2007) in California, Salmon River in central Idaho (Isaak and Thurow, 2006), and Moosach River of the Danube River basin in Germany (Pulg et al, 2013). Other studies addressed importance of hydraulic indicators such as velocity and water depth under low flow conditions (Ishida, 1961, and Chibana and Tmai, 2012), etc. These static indicators may be adopted for relatively small rivers. However, another approach is needed for gravel braided rivers: where representative grain size are larger than those of suitable spawning redds and the riverbed change often occurs within a large river corridor; or where flow and sediment regimes have been altered by interventions for flood and water resources management.

A number of Ayu used to habitat in the Tenryu River, however they have been reduced. Some reasons could be riverbed degradation due to gravel mining, reduced sediment supply from upstream and turbid flow discharge due to dam construction, etc., negatively affecting the spawning redds.

Even though larval drift of Ayu was observed with high density in the Tenryu River, the spawning redds have never been found before 2013 in spite of considerable efforts in exploring riffles in the main channels in corporation with the Tenryu River fishermen's corporative. However, in our recent field investigations in 2013 and 2014, we found the spawning redds in the spring channels and analyzed the formation processes of the suitable conditions for the spawning redds by dynamic indicators (Hyodo et al, 2014). In addition, a role of instream springs in filtering fine sediment has been addressed to provide an adequate quality of water for spawning redds (Hyodo et al, 2018, and Izumi et al, 2016). Objective of this study is to analyze relationship between hydro-geomorphological formation processes and distribution of suitable spawning sites for Ayu in the Tenryu River.

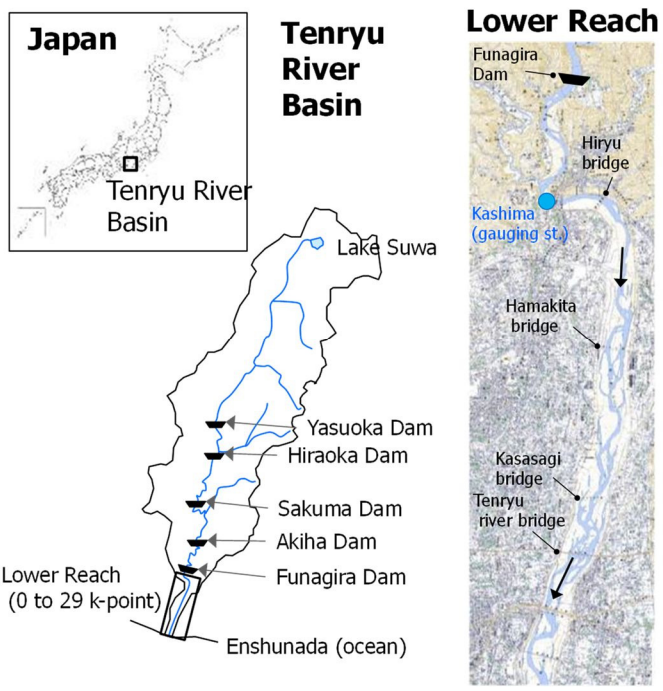

Figure 1. Location of the Tenryu River and study site.

2. METHODOLOGY

2.1 Survey on spawning sites

We conducted surveys on exploring spawning redds of Ayu in 10 to 12 November 2018, and 13 to 17 November 2019. The targeted area of this survey is concentrated at 7 to 17 k-point (i.e., distance from the river mouth), where larval drift has been observed. However, it is noted that this survey does not look much in riffles of the main channels, but in riffles of the spring channels in the gravel bars based on results of our previous study (Hyodo et al, 2014).

2.2 Analysis on changing patterns of riverbed by floods

We analyzed relationship between changing patterns of channel geomorphology by floods and location of spawning sites, using aerial photos and satellite images. Photos and images taken before the survey were analyzed to find relation between geomorphological changes and location of the spawning sites found in 2018 and 2019. As for the survey in November 2018, photos in 22 October 2018, 25 February 2017, and 7 November 2016 were analyzed. As for the survey in 10 November 2019, 28 February 2019, and 22 October 2018 were used for the analysis.

Terrestrial and surface-water boundaries were extracted to identify sandbars in the photo and image data. Then sandbars at two different dates were superposed to identify deposited and eroded area against the geomorphic features at initial sandbars. Figure 2 shows a discharge hydrograph in 2011 to 2019 in the Kashima gauging station in the Tenryu River. Information about dates on surveys, and aerial photos and satellite images taken were added in the figure.

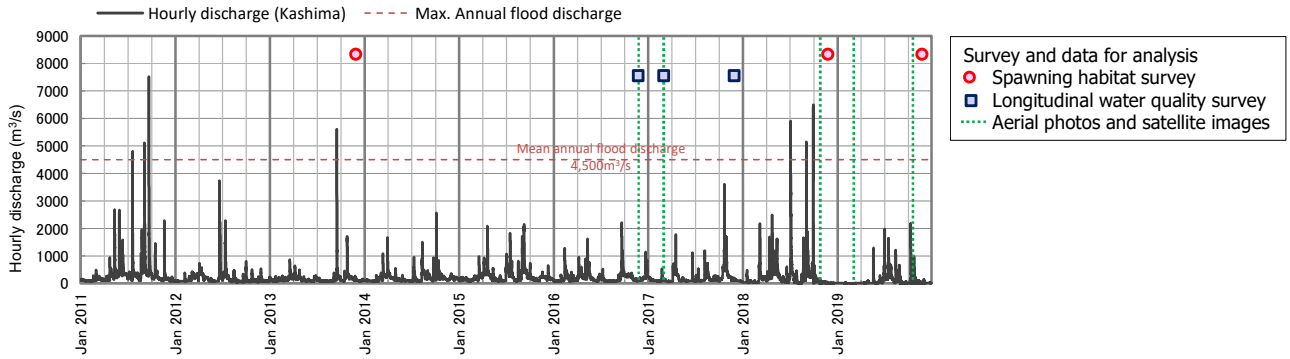

Figure 2. Discharge hydrograph and dates on surveys, and aerial photos and satellite images taken.

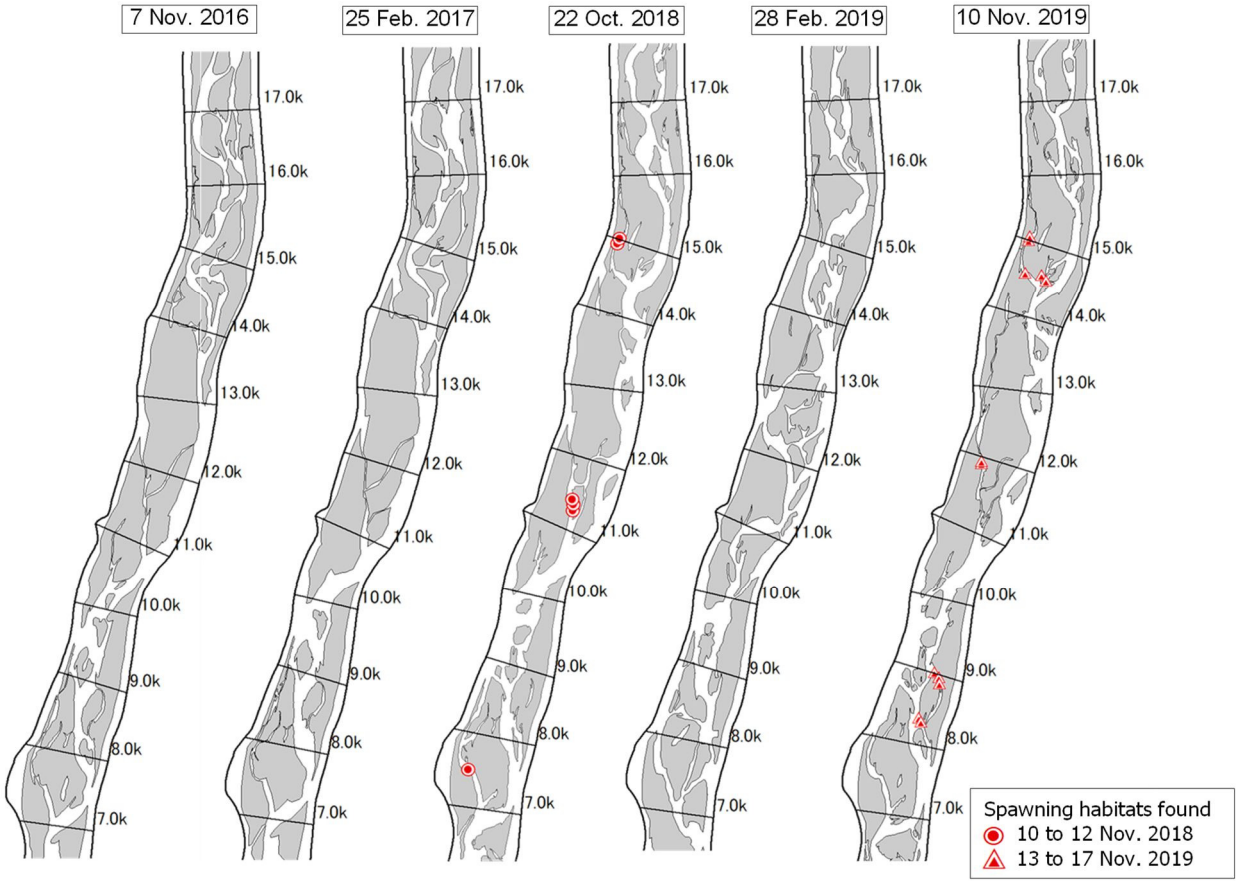

Figure 3. Yearly changes in the channel geomorphology and locations of spawning sites for Ayu found in 2018 and 2019.

2.3 Longitudinal profiles of turbidity of main channels

Surveys on water quality were conducted on 7 November 2016, 19 February 2017, and 28 November 2017 from 0 k-point to 30 k-point (at Funagira dam), of which the one on 19 February 2017 was conducted just after a set of large floods occurred in 2017. The survey itself was conducted and its results were discussed by Takahashi et al (2017, 2018 and 2019).We addressed in this article the turbidity and Suspended Solids (SS) and analyzed their longitudinal profiles along the main channels.

3. RESULTS

3.1 Survey on spawning sites

We found a total of 6 spawning sites on 10 to 12 November 2018 and 12 spawning sites on 13 to 17 November 2019 as shown in Figure 3. In our previous study in 2013 only two spawning sites were found (Hyodo et al, 2014). We obtained successful results during this survey as compared with the previous one in 2013. We could not find any spawning sites in riffles of the main channels, whereas all the spawning sites we found were restricted to riffles of the spring channels in the gravel bars..

3.2 Changing patterns of riverbed by floods

Figure 4 shows hydro-geomorphological formation processes of spawning sites for Ayu, using aerial photo and satellite image data. It is revealed that old channels deposited after floods play an important role in creating loose gravel-riverbed with suitable sediment particle size, up-welling zones coming from interstitial systems under gravel bars that can reduce turbidity by trapping fine sediment.

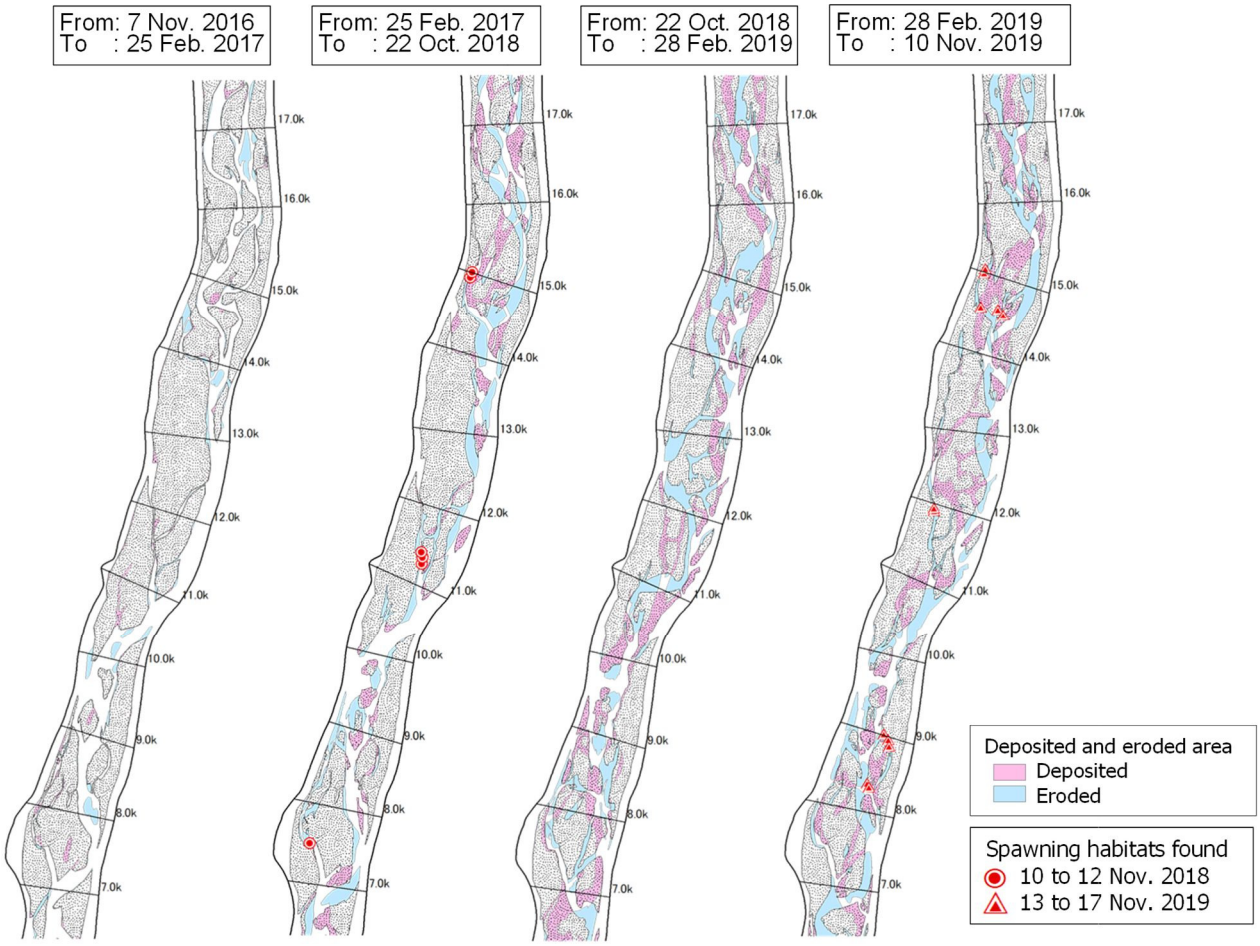

Figure 4. Hydro-geomorphological formation processes of spawning sites for Ayu.

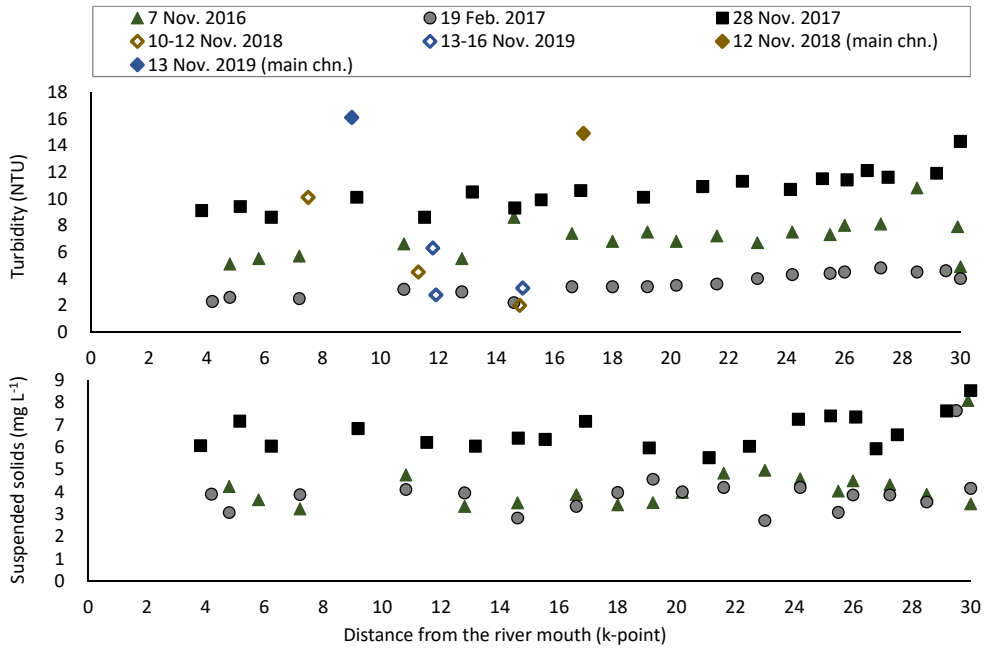

Figure 5. Comparison between turbidity and suspended solids (SS) in main channels and the spawning sites found in the field survey.

3.3 Difference in turbidity and suspended solids between the main channels and the spawning sites.

Figure 5 shows the difference in turbidity and suspended solids (SS) between the main channels and the spawning sites surveyed on 7 November 2016, 19 February 2017, and 28 November 2017 (Takahashi et al, 2017, 2018, and 2019). The result showed that the turbidity and SS were distinctively lower in the spawning sites than in the main channels.

4. DISCUSSION AND CONCLUSIONS

We discussed river channel configuration and morphological processes that maximize suitability of spawning redds under altered river systems. A set of survey results on spawning redds of Ayu since 2013 revealed suitable conditions and locations where would be acceptable for Ayu to spawn under stress in prolong turbidity conditions in the Tenryu River. Physical conditions of suitable spawning redds would be lotic systems with up-welling zones where used to be old channels deposited. These old-channel-made lotic systems play an important role in creating loose gravel riverbed, adequate water quantity with low turbidity, since old channels covered by loose gravels have the function to create upwelling zone and filter fine sediment.

Thus, even though suitable spawning sites are limited due to the turbid water quality, there are still some locations where satisfy conditions for spawning redds in certain geomorphological formation processes in the Tenryu River. Potentially, these locations may have the function as a refugee during floods for fish species. It is important that various habitats and changing patterns of the riverbed with different intensity and frequency of disturbances be consisted of in river reaches. It is important to make use of natural functions of fluvial systems, when balancing among water resources development, flood management and river ecology in an integrated and sustainable manner.

ACKNOWLEDGMENTS

This study was supported by numerous people and organizations such as the Tenryugawa Tennenshigen Saisei Renrakukai (convention on natural resources restoration in the Tenryu River), Tenryu River Fisheries Cooperative, J-Power, Hamamatsu Office of River and National Highway of the Ministry of Land, Infrastructure, Transport and Tourism, and IDEA Consultants, Inc., all of which are acknowledged.

REFERENCES

Brown, R.A., and Pasternack, G.B. (2007), Engineered channel controls limiting spawning habitat rehabilitation success on regulated gravel-bed rivers, Geomorphology, doi:10.1016/j.geomorph.2007.09.012.

Chibana, T., and Tmai, N. (2012). Suitability criteria for fishes focusing on seasonal change of fish habitat, Annual Journal of Hydraulic Engineering, Japan Civil Engineering Society, vol.46, pp.1145-1556 [in Japanese with English synopsis].

Geist, D.R., and Dauble, D.D. (1998). Redd site selection and spawning habitat use by fall chinook salmon: The importance of germorphic features in large rivers, Environmental Management Vol. 22, No.5, pp. 655-669.

Geist, D.R. (2000). Hyporheic discharge of river water unto fall chinook salmon (Oncorhynchus tshawytscha) spawning areas in the Hanford Reach, Columbia river, Canadian Journal of Fisheries and Aquatic Sciences, 5, pp. 1647-1656.

Hyodo, M., Takemon, Y. and Sumi, T. (2014). Relation between riverbed characteristics of spawning redds for Ayuy and the changing habitat in the Tenryu river, Advances in River Engineering, Japan Civil Engineering Society, vol. 20, 67-72 [in Japanese with English synopsis].

Hyodo, M., Takahashi, S., Takemon, Y., and Sumi, T. (2014). Restoring spawning redds for Ayufish by facilitating work on up-welling zone in the Tenryu River, 12th International Symposium on Eco-hydrology 2018, Tokyo, Japan.

Isaak, D.J., and Thurow, R.F. (2006). Network-scale spatial and temporal variation in Chinook sammon (Oncorhynchus tshawytscha) red distributions: patterns inferred from spatially continuous replicate surveys, Canadian Journal of Fisheries and Aquatic Sciences, 63, pp. 285-296.

Ishida, R. (1961). On the spawning of the Ayu, Plecoglossus altivelis, T. & S.-II. Relationships between the size of spawners and the size of gravels of the spawning bed, bulletin of the Japanese Society of Scientific Fisheries, Vol. 27, No. 12, pp. 1052-1057 [in Japanese with English synopsis].

Ishida, R. (1962). On the spawning of the Ayu, Plecoglossus altivelis T. & S.-III. Relationships between the size of spawners and the depth of water of the spawning ground, bulletin of the Japanese Society of Scientific Fisheries, Vol. 28, No. 4, pp. 339-404 [in Japanese with English synopsis].

Ishida, R. (1964). On the spawning of the Ayu, Plecoglossus altivelis T. & S.-IV. Distribution and some geographical features of the spawning ground, bulletin of the Japanese Society of Scientific Fisheries, Vol. 30, No. 6, pp. 478-485 [in Japanese with English synopsis].

Izumi, K., Takemon, Y., Hyodo, M., Kitamura, Y., and Sumi, T. (2016). Restoration of upwelling-zone in a secondary channel for creating spawning reds of Ayu-fish in the Tenryu River, The Journal of Japan Society of Civil Engineers, Ser. B1 Vol.72 , pp. I_439-I_444 [in Japanese with English synopsis].
Pulg, U., Barlaup, B.T., Sternecker, K.S., Trepl, L., and Unfer, G. (2013). Restoration of spawning habitats of Brown trout (Salmo trutta) in a regulated chalk stream, River Research and Applications, 29, pp. 172-182.
Utz, R.M., Mesick, C.F., Cardinale, B.J., and Dunne, T. (2013). How does course gravel augmentation affect early-stage Chinook salmon Oncorhynchus tshawytscha embryonic survivorship?, Journal of Fish Biology, 82, pp. 1484-1406.
Takahashi, S., Hyodo, M., Sumi, T., and Takemon, Y. (2017). Relationship between quantitative and qualitative change of the turbid water and sandbar characteristics in the Tenryu River, DPRI Annuals, No.60 B, pp. 782-790 [in Japanese with English synopsis].
Takahashi, S., Hyodo, M., Yataka, H., Sumi, T., and Takemon, Y. (2018). Quantification of filtering efficiency of sandbar geomorphology based on the longitudinal changes in turbid water component in the Tenryu River, DPRI Annuals, No.61 B, pp. 739-747 [in Japanese with English synopsis].
Takahashi, S., Hyodo, M., Sumi, T., and Takemon, Y. (2019). Effects of previous floods on riverbed function for water purification in the Tenryu River, DPRI Annuals, No.62 B, pp. 700-712 [in Japanese with English synopsis].