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Impact of Baseflow on Fish Community in the Ungcheon Stream, Korea

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ABSTRACT

This study investigated the impact of baseflow on fish community in the Ungcheon stream (16.5 km long) located downstream of the Boryeong Dam, Korea. Based on field monitoring, there were five dominant fish species in the Ungcheon Stream accounting for 75% of the total fish community: *Zacco platypus, Zacco koreanus, Tridentiger brevispinis, Rhinogobius brunneus*, and *Pungtungia herzi*. These five fish species were selected as target species. HydroGeoSphere (HGS) and River2D models were used for hydrologic and hydraulic simulations, respectively. A habitat suitability index model was used to simulate fish habitat. To assess the impact of baseflow, each representative discharge was examined with or without baseflow. The HGS model was used to calculate baseflow within the study reach. This baseflow was observed to increase gradually with longitudinal distance. Validation of the hydraulic model dem onstrated that computed water surface elevated when baseflow was included, which was in good agreement with measured data, as opposed to the result when baseflow was excluded. Composite suitability index distributions and weighted usable area in the study reach were presented for target species. Simulations indicated that the baseflow significantly increased habitat suitability for the entire fish community. These results demonstrate that there should be a substantial focus on the baseflow for physical habitat simulation.

Keywords: Baseflow, Composite suitability index, Fish community, HydroGeoSphere model, Weighted usable area

Introduction

Baseflow in a waterway is defined as groundwater contribution to streamflow. Historically, baseflow and surface water have been perceived and managed as isolated resources. A scientific understanding of the contribution of baseflow to streams and watershed processes is critical when addressing water policy and management issues. Previous studies have emphasized the importance of baseflow intrusion into aquatic ecosystem processes and biodiversity in rivers (Beatty *et al*., 2010; Malcolm *et al*., 2004; Power *et al*., 1999). Baseflow often influences the surface channel and hyporheic zones that maintain stream productivity, provide habitat availability, facilitate aquatic species migration, and influence water quality (Malcolm *et al*., 2004; Power *et al*., 1999; Vrdoljak & Hart, 2007). The degree of baseflow dependency is important to maintain compositions and functions of aquatic ecosystems (Hatton & Evans, 1998; Humphreys, 2006; Murray *et al*., 2003).

At present, baseflow cannot be measured using direct methods. As such, it is commonly estimated using a variety of indirect methods (Hall, 1968; Smakhtin, 2001; Tallaksen, 1995). The conventional approach to assess baseflow is typically based on the analysis of a hydrograph over a long-term period, such as the displacement recession curve technique (Rutledge & Mesko, 1996), curve-fitting method (Molugaram *et al*., 2017), Water Table Fluctuation (WTF) method (Healy & Cook, 2002), hydrograph-separation method (Pettyjohn & Henning, 1979; Sloto & Crouse, 1996), the program PART (Rutledge, 1998), baseflow separation method (BaseFlow, BFlow) (Arnold & Allen, 1999), and web Geographic Information Systems (GIS)-based Hydrograph Analysis Tool (Lim *et al*., 2005). There are several fundamental assumptions underlying these analysis methods. However, these assumptions are not always correct. An alternative to these approaches is the use of computational flow dynamics analysis. This approach may be used to identify detailed mechanisms

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associated with the entire terrestrial portion of the hydrologic cycle (Hwang *et al*., 2014; Therrien *et al*., 2010).

Flow regulated by an upstream impoundment can change the natural flow regime and alter surface and sub-surface waters, which is extremely different from the natural flow regime. Flow regimes might also be altered through the pumping or extraction of surface water and groundwater (Beatty *et al*., 2010; Richter *et al*., 1996; Wills *et al*., 2006). Of all environmental changes that occur from impoundments, changes to the flow regime can disrupt habitat connectivity and freshwater biodiversity in reaches downstream of these impoundments (Poff *et al*., 1997; Postel & Richter, 2003). Physical habitat simulations have been used to investigate the impact of these environmental changes on aquatic ecosystems. They have been largely applied to various environmental issues such as river restoration (Booker & Dunbar, 2004; Im *et al*., 2011; Moir *et al*., 2005), the estimation of environmental flows (Ceola *et al*., 2018; Im *et al*., 2018; Mcgregor *et al*., 2018), and the impact of hydraulic structures (Boavida *et al*., 2015; Choi & Choi, 2018; Kang & Choi, 2018; Yi *et al*., 2014; Zolezzi *et al*., 2011). However, the impact of baseflow on both changes in stream flow and aquatic ecosystems has rarely been investigated. This is the rationale underpinning the present study.

This study aims to investigate the impact of baseflow on fish habitats downstream of an impoundment using physical habitat simulation. The study area consisted of a 16.5 km reach downstream of the Boryeong Dam, Korea. Results from fish monitoring showed that there were five dominant fish species in the study reach: *Zacco platypus*, *Zacco koreanus*, *Tridentiger brevispinis*, *Rhinogobius brunneus*, and *Pungtungia herzi*. The HydroGeoSphere (HGS) model was used to optimize baseflow from the seepage of groundwater into the river. Additionally, River2D and Habitat Suitability Index (HSI) model were used for hydraulic and habitat simulations, respectively. Habitat Suitability Curves (HSCs) of target species were constructed using the method described by Gosse (1982). The hydraulic model was validated by comparing the predicted flow with measured data. Two habitat variables, flow depth and velocity, were used in physical habitat simulations. Composite Suitability Index (CSI) and Weighted Usable Area (WUA) under two scenarios, dam discharge (no baseflow) and dam discharge with baseflow, were compared and discussed.

Materials and Methods

Study area and monitoring data

Fig. 1 illustrates the study area, a 16.5 km long reach that is downstream from the Boryeong Dam, Korea. The Ungcheon Stream is a tributary of the Geum River that extends from the dam to the closed estuary. The average bed slope of the study reach is approximately 0.00369. This reach is regulated by the Boryeong Dam. The dam was constructed in 1998. It has a total storage of 116.90 $\times 10^6$ m^3. This dam has been releasing water to generate hydroelectric power, accompanied by the intake of river flow for approximately one year. Its discharge rates for drought flow (Q_{355}), low flow (Q_{275}), normal flow (Q_{185}), and averaged-wet flow (Q_{95}) are 0.04, 0.51, 1.39, and 3.28 m^3/s, respectively (Ministry of Land, Transport and Maritime Affairs, 2011). Here, Q_n denotes the average flow discharge that is exceeded on *n* days of the year.

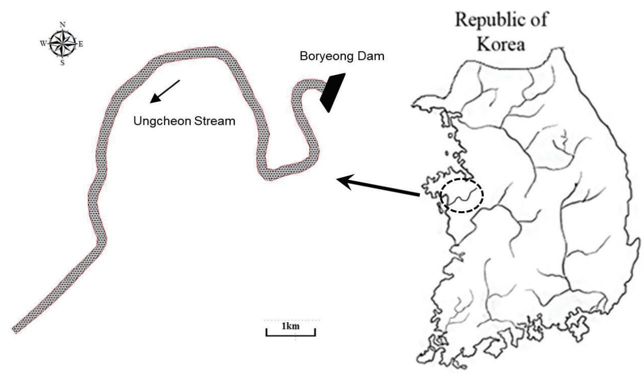

Fig. 1. Study area.

Hydrologic and monitoring datasets for the study reach were collected through government research and development projects for the period of 2007-2010 (Ministry of Land, Transport and Maritime Affairs, 2011; Ministry of Science and Technology, 2007). Monitoring data included information on the date, flow depth, velocity, substrate, and number of individuals. Fish monitoring in the field was conducted using cast nets and kick nets within the study reach. This monitoring found that there were five dominant fish species in the study reach: *Z. platypus* (31%), *Z. koreanus* (16%), *T. brevispinis* (15%), *R. brunneus* (8%), and *P. herzi* (5%). These species accounted for 75% of the total fish community within the study reach. It is often assumed that distributions of fish species have respective data prevalence. For this reason, these five fish species were selected as the target species in this study.

Hydraulic and hydrologic simulation

The River2D model was used to simulate hydraulic conditions in the study reach. The model was developed by Steffler and Blackburn (2002) at the University of Alberta in Canada. The River2D model can solve two dimensional (2D) depth-averaged hydrodynamic equations using the finite element method (Steffler & Blackburn, 2002). The continuity and momentum equations in the x-y horizontal plane can be expressed using Equations (1) to (3):

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

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

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

where t is the time; x and y are stream-wise and transverse directions, respectively; H is the flow depth; U and V are depth-averaged velocities in x-and y-directions, respectively; $q_x(=HU)$ and $q_y(=HV)$ are respective unit discharges in x-and y-directions, respectively; S_{0i} and S_{fi} are the friction slope in x- and y-directions, respectively; g is gravitational acceleration; p is water density; and T_{ij} is the horizontal stress tensor. The x and y components of the friction slope were estimated using Equations (4) and (5):

$$S_{fx} = \frac{n^2\, U\sqrt{U^2+V^2}}{H^{4/3}} \quad (4)$$

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

where n was the Manning's roughness coefficient.

The HGS mode was used for hydrologic simulation. This model is an integrated surface water, variably saturated baseflow, and transport simulator developed by Therrien *et al*. (2010). The HGS model is a three-dimensional (3D) control-volume finite element simulator designed to simulate the entire terrestrial portion of the hydrologic cycle (Hwang *et al*., 2014; Therrien *et al*., 2010).

Validation of the HGS model was performed using an approach described by Hyun *et al*. (2017). To validate the HGS model, various results such as groundwater depth related to hydraulic conductivity, flow rate, and reservoir water level were compared with measured data (Hyun *et al*., 2017). A steady-state model was investigated to estimate baseflow changes in the study reach. It was calibrated with field measurements. The simulated baseflow from the HGS model was inputted into the River2D model to analyze the flow depth and velocity.

Fig. 2 shows changes in discharge along the downstream direction. This figure plots two distributions for different discharges such as the averaged dam discharge (no baseflow) and the averaged dam discharge with baseflow. The dam discharge with the baseflow profile was computed using the HGS model. Fig. 2 shows that in general, the baseflow increases gradually with longitudinal distance. This figure also showed that although the volume and rate of baseflow changed from time to time, the averaged release from the dam was maintained at all time at approximately 2.66 m^3/s. Baseflow is known to play an important role in maintaining biodiversity, habitat connectivity, and ecosystem integrity in rivers (Beatty *et al*., 2010; Danehy *et al*., 2017; Hitchman *et al*., 2018; Isaak *et al*., 2007).

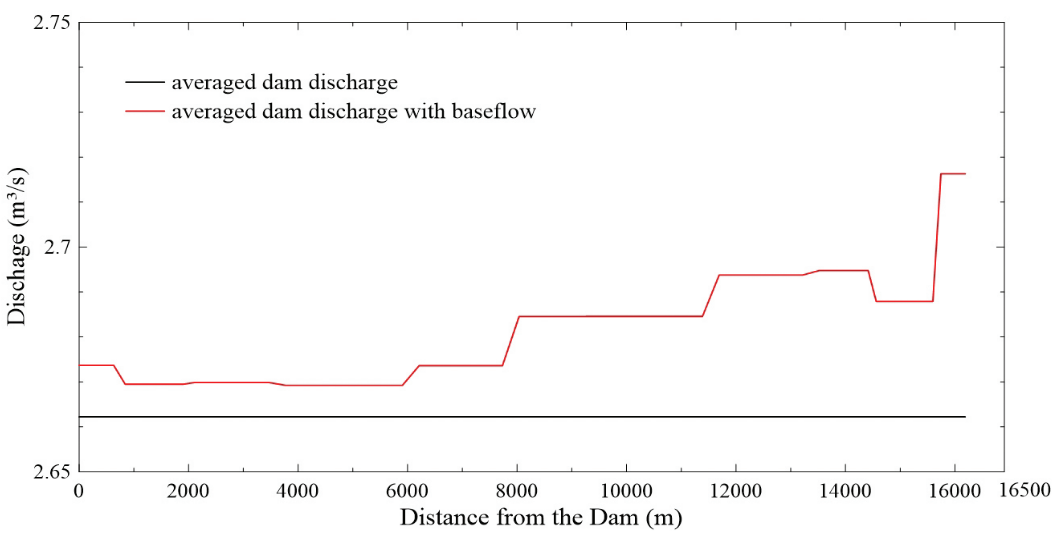

Fig. 2. Longitudinal distribution of discharge.

Habitat simulation

The HSI model was used to perform habitat simulation for fish and benthic macroinvertebrates, in which the model described the relationship between habitat variables and habitat suitability. The HSI model is a numerical tool that can quantify habitats for target species, with HIS ranging from 0 to 1 representing unsuitable and optimal habitats, respectively (US Fish and Wildlife S ervice, 1981). The HSCs for the target species were constructed using a method described by Gosse (1982). We evaluated the HSI model based on the range and distribution of the calculated suitability index. This method gives suitability index values of 1.0, 0.5, 0.1, and 0.05 to the range of habitat variable (flow depth and velocity) that encompasses 50%, 75%, 90%, and 95% of the number of individuals, respectively.

The WUA spatially integrates values of the HSI. It can be computed with Equation (6):

$$WUA = \sum_j CSI_j A_j \tag{6}$$

where CSI_j is the combined suitability index for velocity and flow depth ($HSI_v \times HSI_H$), and A_j is the area of the j-th computation cell. To calculate the WUA in Equation (6), a multiplicative aggregation method was used with two habitat variables (i.e., flow depth and velocity). The stream substrate was excluded from the analysis as the target species did not have a clear preference for a specific substrate (Choi & Choi, 2015; Hur *et al*., 2011; Hur & Seo, 2011; Yeom *et al*., 2007).

Prior to performing physical habitat simulations, HSCs for each target species were constructed using the method described by Gosse (1982). Results are shown in Fig. 3. These HSCs could later be used to predict CSIs using the multiplicative aggregation method. The total number of data points for the constructed HSCs was 2395. The total number of monitored individuals was plotted in the equally-divided range for each habitat variable in Fig. 3. Table 1 summarizes the preferred range for each habitat variable. Target fish species were grouped into three categories: (1) *Z. platypus* and *R. brunneus* known to prefer runs; (2) *Z. koreanus* and *P. herzi* known to prefer riffles; (3) *T. brevispinis* known to prefer pools (Hur *et al*., 2011; Hur & Seo, 2011). For target species that favored runs, preferred ranges for flow depth and velocity were 0.15 – 0.30 m and 0 – 0.40 m/s, respectively. Preferred ranges for flow depth and velocity for target species favoring riffles were 0.15 – 0.45 m and 0.00 - 0.25 m/s, respectively. For the target species that favored pools, preferred ranges for flow depth and velocity were 0.35 – 0.70 m and 0 – 0.20 m/s, respectively. These preference ranges for each type of hydraulic habitat demonstrated clear differences in ranges applicable to flow depth and velocity.

Table 1. Target species and their preferred ranges of physical habitat variables

species	flow depth (m)	Velocity (m/s)	Remark
Zacco platypus	0.25 – 0.30	0.00 – 0.40	Run
Zacco koreanus	0.15 - 0.41	0.00 – 0.25	Riffle
Tridentiger brevispinis	0.35 – 0.70	0.00 – 0.20	Pool
Rhinogobius brunneus	0.15 – 0.25	0.18 – 0.40	Run
Pungtungia herzi	0.30 – 0.45	0.00 – 0.25	Riffle

Results and Discussion

Fig. 4 presents water surface elevation and velocity distributions in the study area. Fig. 4(a) presents longitudinal distribution of water surface elevation with or without baseflow for the downstream direction. Distributions for the water surface elevation on September 18, 2012 and June 04, 2013 were obtained and compared. The water released from the dam had a volume flow rate of 21.3m^3/s on September 18, 2012 and 11.2m^3/s on June 04, 2013. For stage measurements, six stations located 2.92, 6.11, 9.17, 12.25, 14.46, and 15.56 km downstream from the Boryeong Dam were used. To measure water surface elevation, radar water and air purge level gauges were utilized. The predicted water surface elevation was averaged over the width. The river water intake and groundwater were located between 3.2 and 11.4 km downstream from the dam. There were five sites (namely Samgok, Subu, Subu-2, Nocheon, and Nocheon-3) for water intake in the study reach, accounting for approximately 0.35 m^3/s of water. The calibrated roughness coefficient for different field flow conditions and the proposed Manning's n range of 0.030-0.046 were adopted. Results showed that the predicted water surface elevation without baseflow was underestimated compared to measured data at 2.92, 14.46, and 15.56 km, but not underestimated compared to measured data at 6.11, 9.17, or 12.25 km. The averaged relative error between the predicted and measured data was 8.16%. However, the predicted water surface elevation when baseflow was included showed a good agreement with the measured data. This indicated that baseflow compensated the difference between dam discharge and water intake in the river. Fig. 4(b) shows computed distribution of the depth-averaged velocity on June 4, 2013. Here, velocity distributions obtained from the hydraulic simulation with and without baseflow were compared. On June 4, 2013, the velocity ranged from 0.0 to 1.5 m/s at a dam discharge of 11.2 m^3/s. Fig. 4(b) illustrates a general trend in which the velocity distribution is lower than the velocity distribution with baseflow when baseflow is excluded. This indicates that the inclusion of

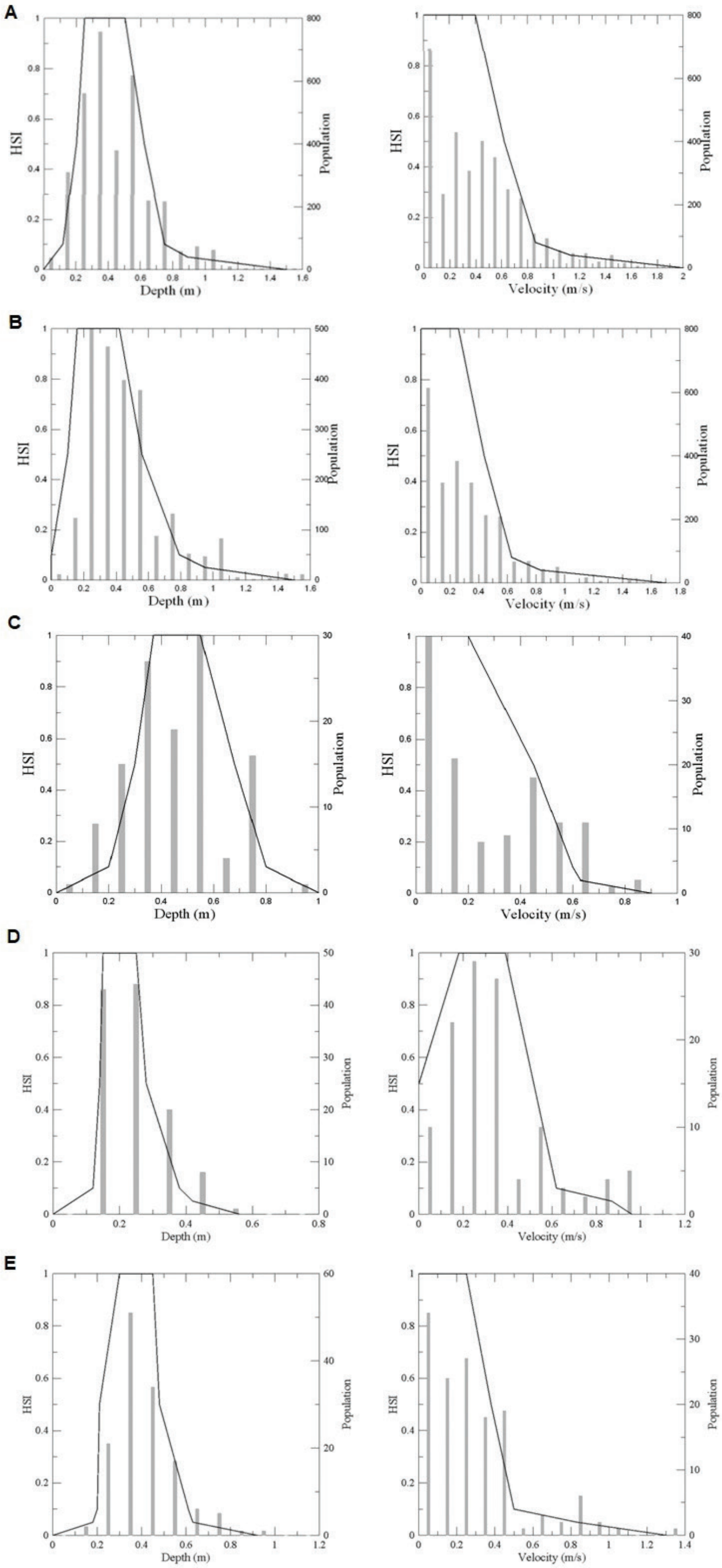

Fig. 3. Habitat suitability curves for target species; (A) *Zacco platypus*, (B) *Zacco koreanus*, (C) *Tridentiger brevispinis*, (D) *Rhinogobius brunneus*, (E) *Pungtungia herzi*.

baseflow can lead to significant improvements in predictions from the 2D flow model largely by reducing the number of under- or over-predictions. Notably, these results emphasize that the baseflow effect should be considered in hydraulic simulations. It is anticipated that the baseflow and water extraction for human activities will affect CSI and WUA for the target species.

To observe the model performance during validation, Mean Absolute Percent Errors (MAPE) were calculated:

$$MAPE = \frac{1}{n}\sum \frac{|H^m - H^p|}{H^m} \times 100(\%) \quad (7)$$

where H^p and H^m were predicted and measured flow depths, respectively.

Fig. 5 shows the predicted versus measured flow Distributions of water surface elevation and velocity; (A) Longitudinal distribution of the cross section-averaged water surface elevation, (B) Distribution of velocity. depths to

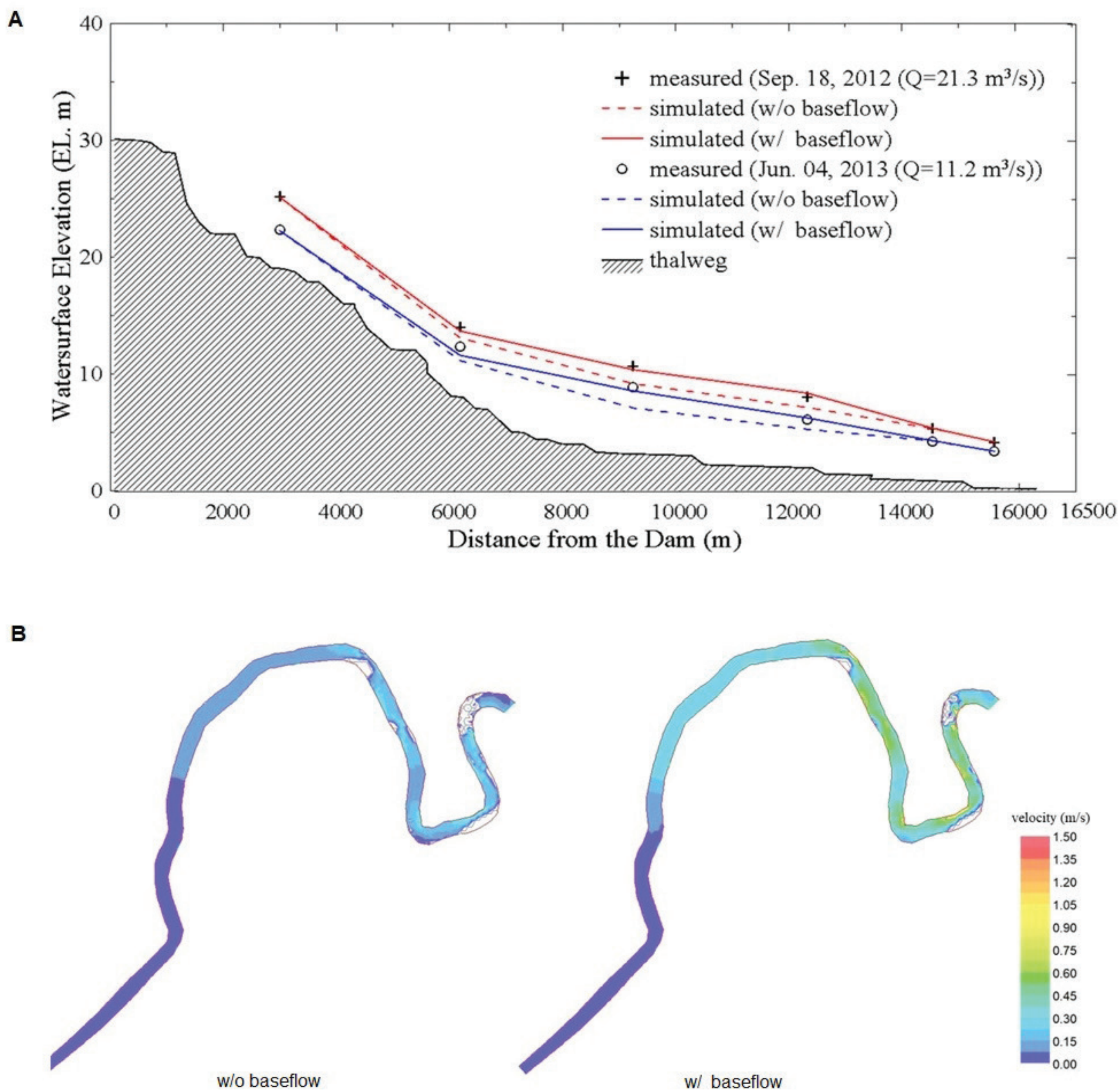

Fig. 4. Distributions of water surface elevation and velocity; (a) Longitudinal distribution of the cross section-averaged water surface elevation, (b) Distribution of velocity.

validate the 2D flow model. In Fig. 5, the validation data were sourced from Fig. 3. The 45-degree line indicated a perfect agreement. Predicted flow depths with and without baseflow are marked by open circles and crosses. MAPE values for the two scenarios were 4.12% and 11.68%, respectively. This indicates that the 2D flow model can predict flow depths very accurately when baseflow is included.

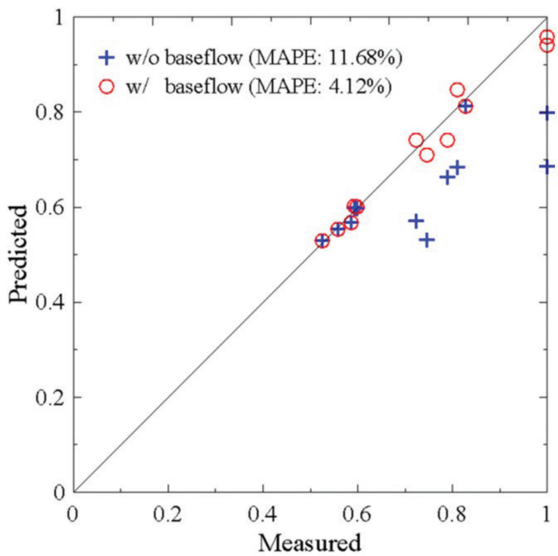

Fig. 5. Predicted versus measured flow depth.

Fig. 6 shows dam discharge without baseflow and dam discharge with baseflow in the study reach. The discharge data in Fig. 6 consisted of observed and calculated values aligning to the dam discharge without baseflow and dam discharge with baseflow, respectively, for 2015. Time series data of the dam discharge were used as references. Fig. 6 shows that the dam discharges 2.66 m^3/s for both hydroelectric power generation and water supply throughout the year. The dam discharge with baseflow was approximately 3.73 m^3/s, which meant the total discharge of inflow to Ungcheon Stream was 1.1 m^3/s. Baseflow is known to affect biodiversity and ecosystem integrity in streams (Beatty *et al*., 2010; Danehy *et al*., 2017; Hitchman *et al*., 2018; Isaak *et al*., 2007). It is expected to maintain habitat connectivity and suitability for the target species.

Fig. 7 shows CSI distributions predicted by the HSI model for dam discharge without baseflow and dam discharge with baseflow. Combined with HSCs shown in Fig. 5, CSIs for the target species were predicted using the multiplicative aggregation method. CSI ranges from 0 to 1, indicating the poorest and the most optimal habitat conditions, respectively. Predicted CSI distributions were averaged over the year. As shown in Fig. 7, CSI with baseflow was significantly higher than that without baseflow. Interestingly, habitats for the target species were more widely

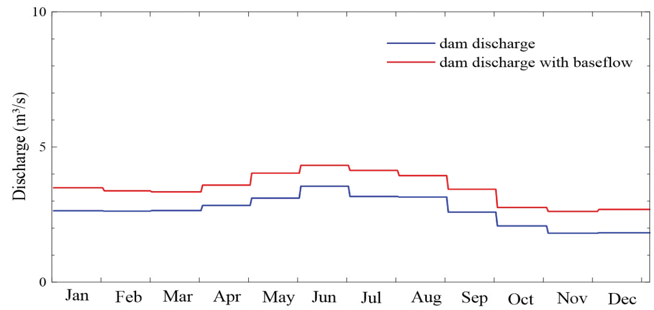

Fig. 6. Dam discharge and dam discharge with baseflow.

distributed when there was a baseflow compared to those when there was no baseflow. This was because the dam discharge at the upstream end and the baseflow at each node in the study reach were considered. *R. brunneus* inhabits midstream and downstream reaches. They prefer shallow water and high velocity. This means that when baseflow is considered, the velocity increases, which improves the habitat suitability. For *Z. platypus* and *Z. koreanus*, their habitat suitability was high in the river bend. Results also showed that habitat suitability was under-estimated for these three target species because the flow depth and velocity were in favorable ranges of these target species. However, for other species such as *T. brevispinis* and *P. herzi*, the overall habitat was not significant. This is because they are lentic fish that prefer deep water and low velocity. These results indicate that physical habitats of *R. brunneus* and *T. brevispinis* are the most and least affected by the baseflow, respectively. These results also highlight that baseflow has a significant effect on habitat suitability and connectivity, consistent with findings from previous studies (Beatty *et al*., 2010; Hitchman *et al*., 2018).

Fig. 8 presents changes in WUA with discharge for the target species. Fig. 8(a) and 8(e) illustrate the WUA for each species predicted with the conventional HSI model. This prediction was based on HSCs shown in Fig. 5, the CSI using the multiplicative aggregation method, and the WUA for each target species. In general, the HSI model without baseflow significantly under-estimated the WUA when compared with the HSI model with baseflow. However, for each target species, discharges that yielded the maximum WUAs were almost identical. The WUA with baseflow was larger than that without baseflow, consistent with results shown in Fig. 7. Quantitatively, dam discharge with baseflow increased the WUA by approximately 13.69%, 15.26%, 9.36%, 19.88%, and 10.98% for *Z. platypus*, *Z. koreanus*, *T. brevispinis*, *R. brunneus*, and *P. herzi*, respectively. This indicates that the effect of baseflow should be considered in the assessment of aquatic habitat suitability, particularly for streams that are heavily influenced by baseflow.

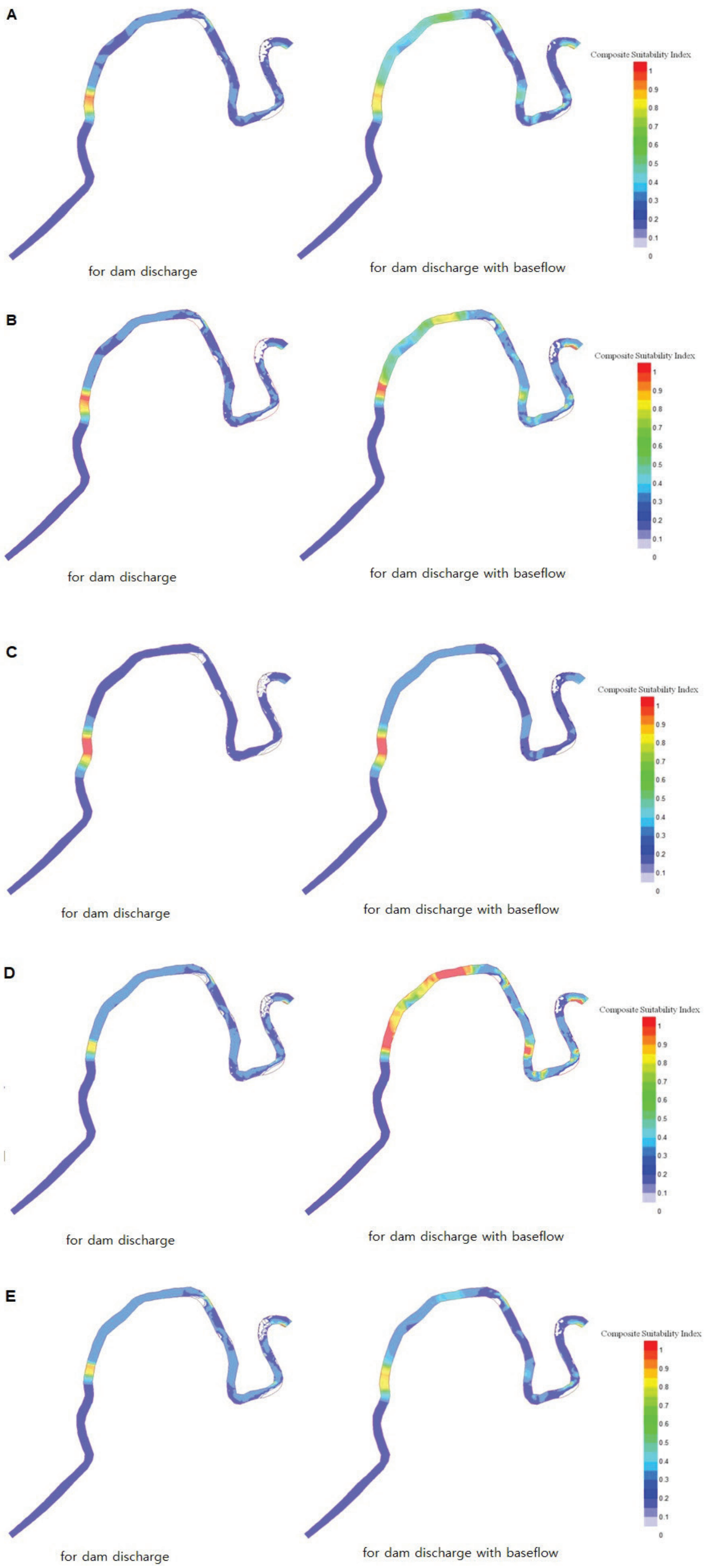

Fig. 7. The CSI distributions for the target species; (A) *Zacco platypus*, (B) *Zacco koreanus*, (C) *Tridentiger brevispinis*, (D) *Rhinogobius brunneus*, (E) *Pungtungia herzi*.

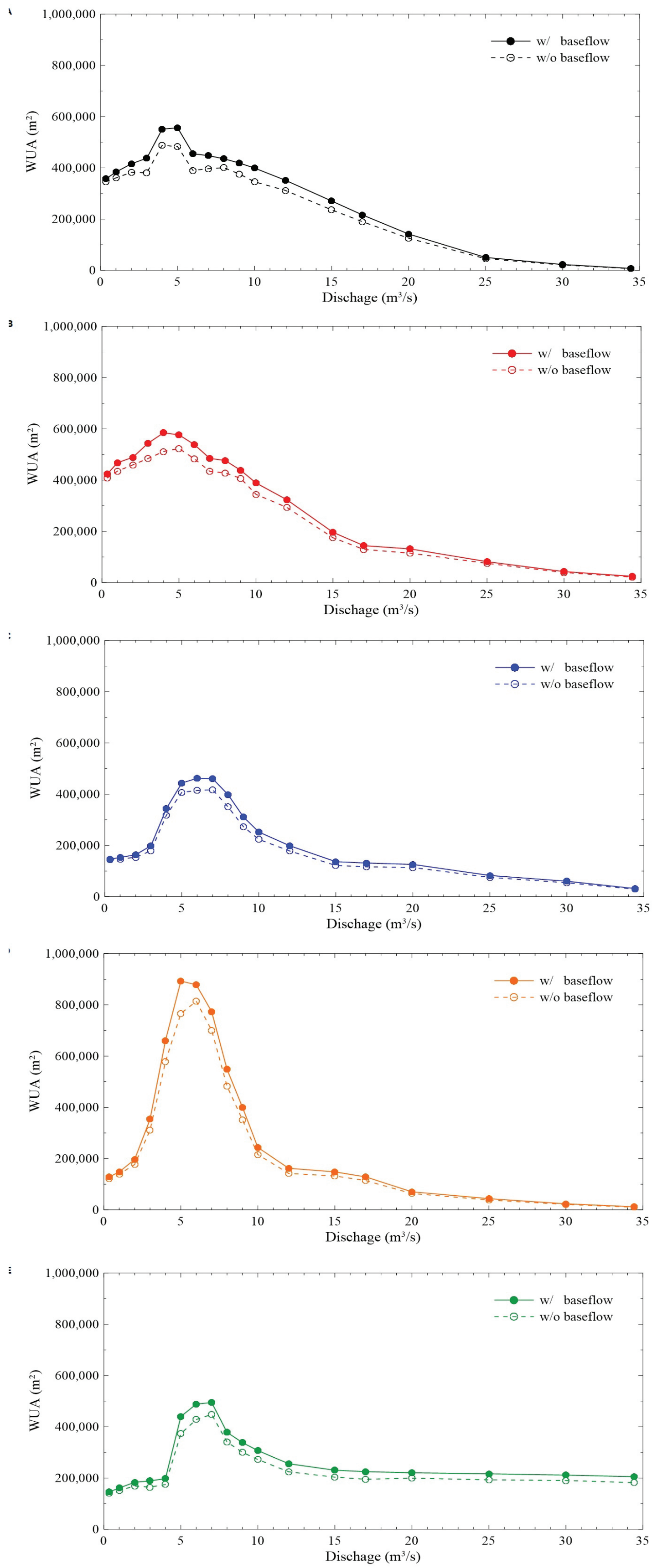

Fig. 8. Change of WUA with discharge; (A) *Zacco platypus*, (B) *Zacco koreanus*, (C) *Tridentiger brevispinis*, (D) *Rhinogobius brunneus*, (E) *Pungtungia herzi*.

Conclusions

This study investigated the impact of baseflow on downstream fish community habitat in a reach regulated by a dam. The study area consisted of a 16.5 km reach located downstream of the Boryeong Dam, Korea. Results from fish monitoring showed that the reach contained five dominant fish species (*Z. platypus*, *Z. koreanus*, *T. brevispinis*, *R. brunneus*, and *P. herzi*) which accounted for 75% of the total fish community. These five species were selected as the target fish species in this study. The HGS and River2D models were used to predict flow. The HSI model was used for habitat simulation. Two habitat variables, flow depth and velocity, were used in physical habitat simulations.

First, using the HGS model, longitudinal baseflow distributions were determined for the study area. Baseflow was found to increase gradually with longitudinal distance. The total baseflow discharge to the Ungcheon Stream was 1.1 m^3/s. The River2D model was then validated, whereby computed water surface elevations were compared with measured data for two scenarios: dam discharge without baseflow and dam discharge with baseflow. Computed water surface elevations showed good agreement with measured data when baseflow was included. In addition, the computed velocity distribution without baseflow was much lower than that with baseflow. These results highlight the need to consider the effect of baseflow when performing hydraulic simulations.

CSI distributions were plotted for the study reach using he HSI model. CSIs for the target species were predicted using the multiplicative aggregation method. The CSI with baseflow was significantly increased in comparison with that he CSI for dam discharges. Additionally, habitat connectivity for the target species was significantly improved with baseflow. These results demonstrate that the habitat of *R. brunneus* is the most sensitive to baseflow, indicating that baseflow can significantly affect habitat suitability and connectivity.

Results of this study also showed changes in WUA with dam discharge for individual target species. In general, dam discharge without baseflow tended to under-estimate the WUA when compared to dam discharge with baseflow. It was also found that baseflow significantly increased the WUA. On average, the WUA was increased by 13.83% due to baseflow. This indicates that there should be a greater focus on baseflow for physical habitat simulation as the inclusion of baseflow in physical habitat simulation can significantly increase habitat suitability.

Conflict of Interest

The authors declare that they have no competing interest

Acknowledgments

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