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Impacts of hydropeaking and thermopeaking on the downstream habitat in the Dal River, Korea

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ABSTRACT

Dams located upstream only release water during the period of hydropower generation. This induces short-term fluctuations of water discharge in the downstream reach, which is called hydropeaking. As occurs quite often, if the temperature of the water released form the upstream dam is different from the water that is flowing in the downstream reach, the water temperature also tends to show short-term fluctuations, which is called thermopeaking. This study investigates the impacts of both hydropeaking and thermopeaking on the downstream habitat. The study area is a 2.3 km long reach located downstream from the Goesan Dam in the Dal River, Korea. To assess such impacts, this study conducted physical habitat simulations. The CMS-Flow model was used for the computation of the flow and water temperature, and the GEP model for the habitat simulation. Three physical habitat variables, flow depth, velocity, and water temperature, were used. The *Zacco platypus* was selected as the target fish in the study area. Simulation results indicated that the hydropeaking flows significantly reduced both the CSI and the WUA when compared with the natural flow regime. In addition, the use of the water temperature in the physical habitat simulations further decreased both CSI and WUA, indicating that thermopeaking is as important as hydropeaking in this type of assessment.

1. Introduction

During the last century, a large number of dams were built in countries across the globe. According to Allan and Castillo (2007), by the end of 20th century, 45,000 large dams, whose crest height exceeds 15 m, and about 1 million smaller dams were built worldwide. Dams provide humankind with flood control, water resources, and hydropower. However, flow regulation via a dam results in pulsating flows due to hydropower generation as well as the cessation of the flood flow, which is significantly different from the natural flow regime. The change of the flow regime affects both the water quality and the aquatic organisms in the downstream area.

Flows regulated by upstream dams affect the downstream habitat in two different ways. First, the upstream dam releases water only during the period of hydropower generations, resulting in the short-term fluctuations of water discharge in the downstream reach. This is called hydropeaking (Valentin et al., 1996). Second, the temperature of the water released from the upstream dam is likely to be different from the water that is flowing in the downstream reach. That is, in general, water released from the dam is warmer and cooler than water flowing in the winter and summer, respectively. Ward and Stanford (1979) called this phenomenon thermopeaking.

Previous studies have shown that hydropeaking adversely affects the downstream habitat (Booker and Dunbar, 2004; Bowen et al., 1998; Garcia et al., 2011; Valentin et al., 1996). Physical habitat simulations have quantitatively shown that hydropeaking flows reduce habitat availability and suitability for certain aquatic species in the downstream reach (Boavida et al., 2015; Li et al., 2011; Tuhtan et al., 2012). Degradation of the habitat is related to the disruption of natural river flows and channel fragmentation, and it hinders species' reproduction (Shen and Diplas, 2010). That is, only during the short period of hydropower generation, the downstream reach experiences a pulsating flow exceeding or slightly less than the averaged-wet flow, and parts of the downstream reach become dry during the recession period. In addition, the regime change from the natural flow to the fluctuating flow reduces macro-invertebrate populations by exposing them to the sun or forcing them to move to other places. This will indirectly affect the downstream fish habitat.

Similarly, field investigations have reported that thermopeaking has a major effect on biotic distributions by stimulating behavioral responses in aquatic animals (Lessard and Hayes, 2003; Zolezzi et al., 2011). Dickson et al. (2012) pointed out that the change of the

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temperature regime alters the life cycle duration, insect emergence timing, drift, and mortality rate of invertebrates. That is, it affects the hatching periods, the onset of adult insects, and the growth rates of certain invertebrates (Céréghino et al., 1997; Hogg and Williams, 1996). Moreover, changes in the water temperature affect the oxygen concentration of water, resulting in a change in the drift rate (Brittain and Eikeland, 1988), and the functional structures of the invertebrate communities are strongly affected by the water temperature in the stream (Cox and Rutherford, 2000). However, most previous physical habitat simulations have not taken thermopeaking into account when assessing the effect that hydropeaking flows have on the downstream habitat (Boavida et al., 2015; Gibbins and Acornley, 2000; Shen and Diplas, 2010).

The present study aimed to investigate the impact of both hydropeaking and thermopeaking on the downstream habitat using a physical habitat simulation. For this, a 2.3 km long reach located downstream from the Goesan Dam was selected for the study reach and *Zacco platypus* was selected as the target species. The CMS (Costal Modeling System)-Flow model and the GEP (Gene Expression Programming) model were used for the hydraulic and habitat simulations, respectively. The CMS-Flow model was validated by comparing the predicted flow and the water temperature with the measured data. Three habitat variables, flow depth, velocity, and water temperature, were used in the physical habitat simulations. The CSI (Composite Suitability Index) and WUA (Weighted Usable Area) under hydropeaking operations were computed, and they are discussed.

1.1. Study area and target fish

The study area is located downstream from the Goesan Dam in Korea as shown in Fig. 1. The dam was constructed in 1957 and it has a total storage of 1.53×10^6 m^3. The study reach is 2.3 km long, extending from the Sujeon Bridge to the Daesu Weir. The reach includes a bend, and the average slope is 1/650. The Goesan Dam, 0.92 km upstream from the Sujeon Bridge, regulates the flow in the study reach. For the study reach, the discharges for drought flow (Q_{355}), low flow (Q_{275}), normal flow (Q_{185}), and averaged-wet flow (Q_{95}) are 1.82 m^3/s, 4.02 m^3/s, 7.23 m^3/s, and 17.13 m^3/s, respectively (Ministry of Construction and Transportation, 1995). Here, Q_n denotes the average discharge which is exceeded on *n* days of the year.

Through field investigations, Kim et al. (2007) reported that the bed materials for the study reach range from sand to cobble. The median size of the bed material is 137 mm, indicating that the study reach is a gravel-bed stream. A riffle is located around the apex of the bend and pools are present before and after the riffle. Kim et al. (2007) reported that the bed materials at the riffle and pools consist of coarse and fine particles, respectively. The median size of the bed sediment in the riffle is 166 mm, and the bed sediment in the pool ranges between 60 mm and 120 mm (Kim et al., 2007).

Fish monitoring by Kim et al. (2007) revealed that dominant species in the study area is *Zacco platypus*, followed by *Zacco temminckii* and *Coreoleuciscus splendidus*. They account for 27%, 15%, and 15%, respectively. In the present study, the adult *Zacco platypus* was selected as the target fish and abundance data were used in the evaluation of the physical habitat. Adult *Zacco platypus* is a lotic species, which normally lives in the riffles in the midstream or downstream reach of rivers (Chu et al., 2015; Negishi and Kayaba, 2010). In particular, they are known to adapt relatively well to artificial changes caused by activity on the river. Since the monitoring data includes the number of individuals, flow depth, velocity, substrate, and water temperature, they are habitat use data of Category II based on the criterion by Bovee (1986).

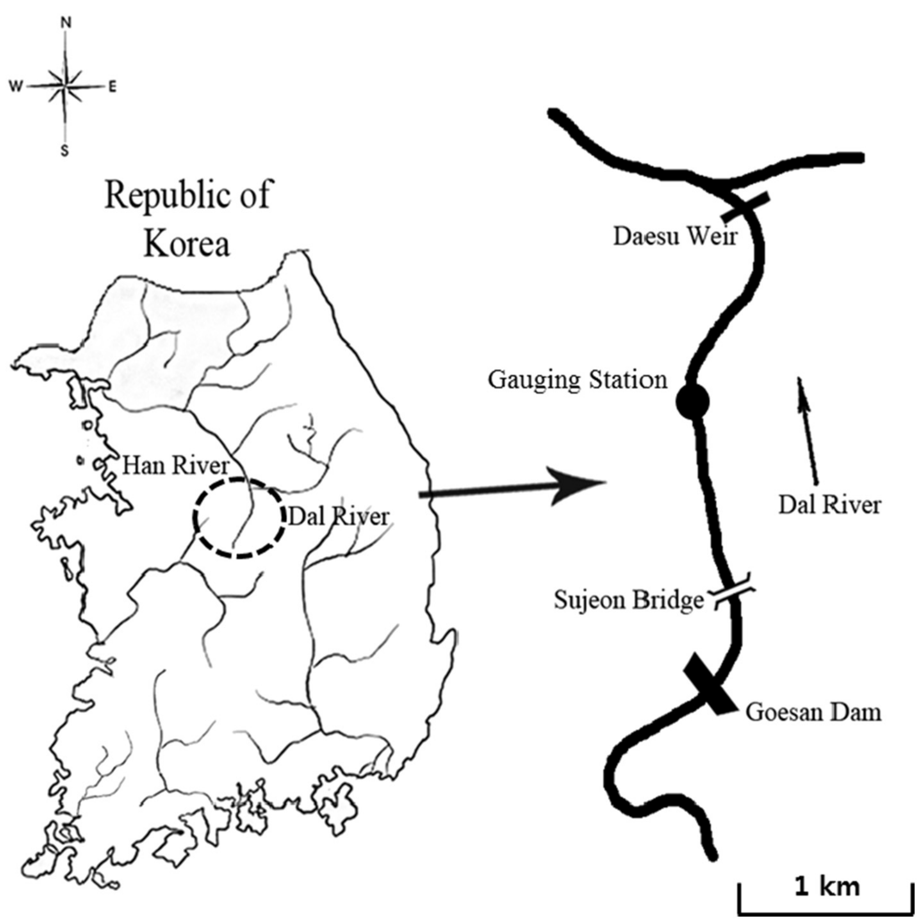

Fig. 1. The study area.