STRANDING OF LARVAL NASE (*CHONDROSTOMA NASUS* L.) FOLLOWING ARTIFICIAL FLOW DOWN-RAMPING UNDER EXPERIMENTAL CONDITIONS

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Artificial sub-daily flow fluctuations during hydropeaking are considered one of the most significant impacts on rivers downstream of dams. They have, therefore, been subject to a growing number of studies in the last decades. Nevertheless, so far, cyprinid fish have hardly been considered worldwide and extensive knowledge gaps remain. Therefore, this study aims to assess the effect of rapid flow reductions on early life stages of common nase (*Chondrostoma nasus* L.) in an experimental approach. Different hydropeaking scenarios were simulated at an outdoor experimental facility (http://hydropeaking.boku.ac.at) using mesocosms (2.25×2 m) mimicking typical larvae habitats to quantify stranding of young-of-the-year nase. Experiments were performed during day and night. At each replicate, 100 fish (body length <20 mm) were stocked at peak flow (80 L.s-1). After an adaption time (15 min.), the discharge was automatically reduced – with variable ramping rates – until constant low flow conditions (10 L.s-1) were reached and stranded fish were recorded. Our analyses show a distinct difference in stranding risk between day and night experiments. Further, the data indicates differences between tested down-ramping rates and interaction effects between time of day and down-ramping rate. The study outcome will benefit the ongoing discussion on hydropeaking mitigation by providing a more profound knowledge of the direct effects of artificial sub-daily flow fluctuations on the early life stages of cyprinid fish.

# INTRODUCTION

Hydropower assumes a leading role among renewable energy sources, and its production is expected to increase due to the growing demand for energy [1]. One particular form of hydropower production is based on peak-operating hydropower plants, acting as load-balancing power sources to store and generate energy on demand, thus accounting for grid fluctuations in other renewable energies [2], [3]. This mode of operation is characterized by frequent daily or sub-daily artificial flow fluctuations in the downstream receiving water body [2], [3].

So called *hydropeaking* is described as one of the key stressors in mountainous rivers [4], altering the natural flow regime [2] and hydraulic factors such as water level, flow velocity, and bed shear stress [5]. During artificial flow increases, fish – particularly larvae and juveniles – seek shelter in shoreline areas to unsuitable hydraulic conditions [6]. After hydropeaking, however, these areas may be dewatered during flow down-ramping, increasing the risk of fish stranding and trapping, depending on various factors including time of day and discharge rate [7].

This study aims to fill the knowledge gap on cyprinid fish species affected by hydropeaking [8] by quantifying, for the first time, the stranding of nase, *Chondrostoma nasus* L., larvae in an experimental approach. In detail, we simulated single down-ramping events in mesocosms, mimicking suitable larval habitats with low flow velocities [9]–[11], to test the effect of (i) varying down-ramping rates (ii) during day and night on stranding of (iii) different larval stages of nase. We hypothesized that stranding would be reduced with lower down-ramping rates. Further, we expected lower stranding during day experiments than night trials, and a higher vulnerability of the earlier larval stage than the older one.

# MATERIAL AND METHODS

We performed the ethohydraulic experiments in May and June 2021, at the ‘*Hydromorphological and Temperature Experimental Channels*’ (HyTEC; <https://hydropeaking.boku.ac.at>). The HyTEC facility comprises two parallel arranged outdoor experimental channels (40 m long and 6 m wide), where the water temperature can be adjusted by controlled mixing of lake water diverted via two pipes at different depths before being discharged to each channel. The mesocosms were embedded opposite each other in the two channels.

Due to the vulnerability of the larvae, experiments were conducted in two mesocosms (2.25×2 m) framed with nets (mesh size: 0.75 mm) and embedded in the HyTEC channels. The flat gravel bank area (the ramping zone) of both mesocosms had a lateral bank slope of 2% and was filled with a sediment layer (1.5 cm), dominated by sand and fine gravel (d50=2.2 mm; d90=6.0 mm). The sediments were smoothed and the nets were checked and cleaned before each experimental run to ensure constant experimental conditions over time.

Within the period of experimentation, water temperatures were consistent with seasonal temperatures in typical habitats of nase (mean=9.9°C±0.9 SD), ranging from 8.5°C to 11.4°C. The length of nase larvae, which originated from wild fish stocks, ranged from 11.0 to 20.0 mm (mean TL=14.1 mm±1.0 SD). Larval development stages were classified *sensu* Peňáz [12], with larvae from the third (III) to fifth (V) larval stage. The first experimental set (May 19th–30th, 2021) with early developmental stages was pooled (stages III-IV) due to the larvae’s similar morphological characteristics showing incomplete developed dorsal, caudal and anal fins [12], and associated challenges in timing the experiments. The second experimental set (June 3rd–16th, 2021) studied larval stage V, with much advanced differentiation of the finfold, fully separated dorsal and anal fin, and a longer caudal fin [12].

The experiments were performed during the day (under daylight conditions, 10:00-18:30) and at night (after sunset, 22:15-02:00) to assess the influence of the photoperiod. The down-ramping experiments were performed according to a repeatable design to quantify the stranding of early life stages of nase: (i) 100 larvae were counted from the rearing tanks and (ii) stocked at high flow (80 L.s-1) in the upper part of the mesocosms around 20 cm from the shore, offering suitable larvae habitats. The water temperature was kept constant between the rearing tanks and mesocosms. Stocking was done gently inclined against the flow, waiting until all larvae had voluntary left the stocking bucket to avoid a flight response of larvae. To prevent stocking-related responses during the down-ramping experiment, (iii) a period of 15 min. with steady flow was specified as acclimation time (based on preliminary experiments). Subsequently, (iv) the high flow was automatically reduced (down-ramping) to the low flow rate of 10 L.s-1 by the control unit of the HyTEC-facility and (v) larvae were quantified according to the location where they were found: stranded on the dewatered substrate; in the nets or on the substrate, but close to the downstream net (≤1cm); remaining swimming in the low flow channel.

For each trial, the frequency of stranded larvae (*Strcalc*) was calculated as follows:

$Str\_{calc} [ind.]=100-\left(N+N^{'}+C\right)$, (1)

whereby *N* is the count of larvae retrieved from the nets, *N’* those found on the substrate close to the downstream net (≤1cm), and *C* is the number of larvae cleared from the low flow channel. Missing individuals were assumed to be stranded but hidden in the substrate and were therefore included for stranding quantifications. Specimens associated to *N* and *N’* were excluded from stranding calculation, as observations revealed that most of them were displaced into the net before down-ramping and were therefore not available for possible stranding.

The frequency of stranded larvae was standardized as risk (*Strrisk*) as follows:

$Str\_{risk} [-]=\frac{Str\_{calc}}{Str\_{calc}+C }$ (2)

To assess differences in stranding between pairs of experimental scenarios (see Figure 1), Yule’s Q, a -1 to +1 transformation of odds ratios (OR), was used, presenting a statistically appropriate approach for the data [13], [14]. We assumed the equivalence of the compared scenarios between ‑0.08 and 0.07 for Yule’s Q. Also, we reported the widely used p-values to express statistical significance by the Cochran–Mantel–Haenszel test (α=0.05).

# RESULTS

We conducted 61 trials from 11 experimental scenarios with larval nase (Figure 1). There was no difference in stranding risk between the two experimental channels (Q=-0.01; 95% CI=-0.07–0.06; p=0.799).

We found significantly higher night stranding rates than during the day across all scenarios (Q=-0.45; 95% CI=-0.52–-0.39; p<0.001). For larval stage III-IV and V, the differences in day- and nighttime stranding were evident (p<0.001 for both larval stages), with stranding rates 2.5 times higher at night than during the day.



Figure 1: Stranding risk depending on the down-ramping rate [0.7–2.0 cm.min-1], daytime [day (D): white; night (N): black], and larval stage [III-IV; V]. The number of replicates (n) is shown at the bottom. The boxplots with the associated bold lines and whiskers refer to median values and interquartile ranges. White squares indicate the mean value.

Figure 2

Furthermore, we found strong evidence that stranding rates for larval stage III-IV was higher than larval stage V (Q=0.59; 95% CI=0.53–0.65; p<0.001) (Figure 1). When comparing both larval stages at the down-ramping rate of 1.5 cm.min-1, we found significantly higher stranding rates for larval stage III-IV compared to larval stage V (Q=0.82; 95% CI=0.76–0.88; p<0.001).

We detected the strongest differences between individual down-ramping rates at larval stage III‑IV (Figure 1). In these cases, all comparisons between individual down-ramping rates were significant (p<0.001). Also, for larval stage V, group differences were evident (p<0.001). Splitting the data by larval stage and time of day also revealed differences for all down-ramping rates (p<0.001), except for the comparison of the down-ramping rates of 1.1 cm.min-1 and 1.5 cm.min-1 during day trials (Q=-0.16; 95% CI=-0.33–0.0; p=0.054).

# DISCUSSION

Our results demonstrate that – similar to salmonid fish [7] – bank dewatering due to artificial flow reduction causes larval nase to strand. In detail, experiments during nighttime lead to almost three times higher stranding than daytime trials. This outcome is in line with several studies, underlining the effect of photophase on fish stranding [7,13-14]. Anyhow, diurnal patterns may vary depending on the season, seasonal temperature, and species, with contrasting directions of effects have been reported in the literature [7], [16], [17].

Considering that early life stages are very sensitive to flow fluctuations [18], [19], we hypothesized that larval stages with incompletely developed fins are more sensitive to stranding than later stages. This assumption was confirmed by the presented experiments, revealing a difference in stranding between larval stages III-IV and V, with more than three times higher stranding rates at the smaller larval stage (TL≈13–14 mm) compared to the larger one (TL≈15–17 mm).

Fish stranding has been observed for several species and life stages to decrease with reduced down-ramping rates [4], [6], [18]. Our experiments emphasize the relationship between stranding risk and down-ramping rate for both larval stages during day and night. In contrast to experiments with salmonids [7], [20], the present study indicates that nase can avoid stranding at high down-ramping rates at comparatively early life stages. This finding is also consistent with our observations during down-ramping, demonstrating that larval nase can avoid stranding even though they shift back and forth laterally close to the shoreline with the receding flow rather than moving immediately to deeper water. This is remarkable, as we assumed that such behavior would increase stranding.

Our results may feed into defining specific mitigation criteria for cyprinid species. We recommend strict ramping thresholds within the first weeks after gravel emergence, especially at night. Further, thresholds for hydropeaking mitigation should be monitored and analyzed to learn more about their implication in supporting healthier fish populations in hydropeaked rivers.

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