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ARTICLE

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Effects of egg stocking on density, distribution, and size of young-of-year brown trout (*Salmo trutta*) in a large boreal river in northern Sweden

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Abstract

An understanding of egg densities and juvenile production is critical in salmonid egg stocking projects, but the question is not deeply studied. Given that managers rely on the number of young of the year (YOY) fish to evaluate stocking success, this knowledge gap poses a major challenge. We studied effects of two stocking levels on YOY brown trout at different downstream distances (0–600 m) from the stocking point. Density increased significantly with increasing distance from the stocking point when 60,000 eggs were stocked but not when 30,000 eggs were stocked. Body length was not related to distance from the stocking point and only moderately negatively related to density. We conclude that the results of egg stocking can be difficult to interpret because site-specific density may vary with distance from the stocking point and the number of eggs stocked.

KEYWORDS
alevin, discharge, dispersal, ova, salmonid, Vindelriver

1 | INTRODUCTION

Salmonid eggs have been widely stocked into the natural environment to reintroduce or enhance populations of salmonids (e.g., Barlaup & Moen, 2001; Coghlan & Ringler, 2004; Kirkland, 2012). However, identifying optimal density for egg stocking to maximize fry production is critical for project success but represents an important knowledge gap. For instance, stocking eggs at a rate that introduces more individuals than the habitat can support may reduce fry survival through intraspecific competition. Additionally, stocking eggs can be expensive and labor-intensive (Johnson, 2004) and sometimes relies on volunteers to implement and maintain. These considerations provide additional incentive to design and scale stocking programs effectively.

Previous research on intraspecific competition in juvenile Atlantic salmonids has provided details on the relationship between fish density, dispersal, growth, and survival based on eggs from both natural and artificial redds (e.g., Einum & Nislow, 2005; Einum et al., 2011; Eisenhauer et al., 2020; Elliott, 1984, 1986, 1994; Milner et al., 2003). Collectively, previous research has shown that the quantity of eggs stocked is positively related to the distance young of the year (YOY) fry disperse and negatively related to growth. However, field studies that focused on YOY Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) dispersal from stocked eggs (e.g., Beall et al., 1994; Einum et al., 2008; Eisenhauer et al., 2020; Palm et al., 2022; Webb et al., 2001) relied on relatively small egg quantities (maximum 15,000 per stocking site) stocked in small streams. Therefore, results of previous research might not fully reflect the outcome of larger egg quantities stocked in larger rivers, which are common (Pers. com., Agren, 2023; Calamnius, 2023). Additional information under different conditions (e.g., larger number of eggs stocked in larger rivers) will provide important information for future egg stocking projects. In northern Europe (i.e., Sweden, Norway, and Finland), many brown trout populations were extirpated or threatened due to anthropogenic activities (Nilsson et al., 2005). In response, numerous restoration projects have been initiated, some of which include stocking of brown trout eggs in large rivers.

Our objective was to determine if egg stocking density affected the density, distribution, and size of YOY brown trout. Our findings should be useful for informing fishery managers in northern Europe and elsewhere about limitations of YOY egg stocking. To achieve our objective, we measured effects of stocked egg quantity on the density, distribution, and size of YOY brown trout in a large boreal river in northern Sweden. Stream-specific recruitment success in brown trout populations has often been evaluated by electrofishing YOY salmonids along a few 20–40 m stream reaches (e.g., Swedish Electrofishing Register—SERS, 2022). Given the limited information on dispersal distance of YOY from stocking points, this posed a major challenge for evaluating artificial production. Increased understanding of how stocking levels (i.e., number of eggs stocked) affect YOY dispersal would enable improved evaluation of stocking success.

2 | METHODS

2.1 | Study area

The study was conducted in a 50-m wide secondary channel to the Laisriver (Laisälven in Swedish), a tributary to the Vindelriver in the boreal region of northern Sweden (Figure 1). The Laisriver catchment that comprises 3000 km^2 is characterized by large seasonal flow variation, with high flows in May–June (max 450 m^3/s) during peak snowmelt and low flows in March–April (min 4 m^3/s). The catchment and fish production is heavily influenced by forestry, including clearcutting and ditching. The river has also been cleared of obstacles, such as large boulders and large woody debris, and channelized to facilitate timber floating (Nilsson et al., 2005), so brown trout stocking was initiated. Fish species include brown trout, Atlantic salmon, European grayling (*Thymallus thymallus*), northern pike (*Esox lucius*), Eurasian perch (*Perca fluviatilis*), Eurasian minnow (*Phoxinus phoxinus*), and burbot (*Lota lota*). In this region, trout spawn in mid-October and YOY fry emerge from the riverbed during late June and early July. In the study area, the abundance of anadromous and resident brown trout was lower than in neighboring rivers due to long-term anthropogenic disturbance. Based on 24 electrofishing events of 2–3 consecutive fish removals during 1990–2015 along the Laisriver mainstem and secondary channel, the average estimated density (mean ± SE) of brown trout was 1.79 YOY/100 m^2 ± 0.46 and 2.98 age-1+/100 m^2 ± 0.41 (Jonsson et al., 1999; Swedish Electrofishing Register—SERS, 2022).

2.2 | Egg stocking

Trout eggs were stocked at a single point in a 1100-m-long secondary channel with run and riffle habitat, gravel-boulder substrate, 50-m mean wetted width, 0.4-m depth, and 0.5% gradient in late August. At the stocking point, 60,000 (2016 and 2017) or 30,000 (2018 and 2019) eyed eggs were stocked annually on 1 day in mid-March. Eggs were first-generation hatchery eggs from the Vindelriver stock obtained from a nearby hatchery. Eggs were fertilized on a single day, and the fertilization date did not vary by more than 1 week among years. Eggs were placed in Whitlock Vibert boxes (hereafter WV boxes) (Barlaup & Moen, 2001), with 2500 eggs per box, in sets of four in gravel-filled perforated plastic crates (Figure 2), placed on the streambed at the stocking point. Water easily circulated around eggs to generate moderate egg movement. Plastic crates were positioned at a single point in the middle of the channel on top of gravel substrate (Figure 1). The presence of gravel substrate where crates were placed indicated that the site was not annually exposed to extreme water velocity and would most likely provide flow conditions suitable for natural spawning. Gravel was not placed inside WV boxes, but boxes were covered by 20 cm of gravel. Gravel was washed and sorted (4–6 cm) to promote high water exchange to maximize egg survival. We assumed that most YOY fry would disperse downstream within 900 m of the stocking location during the study (Beall et al., 1994; Einum et al., 2008; Eisenhauer et al., 2020; Palm et al., 2022; Webb et al., 2001) and would remain in the secondary channel. The wet area of available fry habitat in the secondary channel downstream from the stocking point (29,750 m^2) was measured as a polygon, excluding the dry area of the islands (Figure 1). Egg stocking density was one egg per m^2 at the 30,000 egg stocking level and two eggs per m^2 at the 60,000 egg stocking level. Egg stocking density, if standardized to the area of the entire secondary channel (not only the area downstream of the stocking point), was even lower. Based on stock recruitment studies of Atlantic salmonids, juvenile production peaked at 60 eggs per m^2 for brown trout (parr) (Elliott, 1994) and Atlantic salmon (smolt) (Jonsson et al., 1998). Therefore, stocking densities in our study were assumed to be lower than the maximum sustainable egg density for the area. In mid-July, gravel-filled crates and WV boxes were retrieved and inspected for damage and unhatched eggs.

2.3 | Fry numbers and size

To estimate abundance and body length, YOY trout were sampled in late August at four sites downstream of the stocking point (Figure 1). The four electrofishing sites averaged 46 m in length and 12.5 m in width, and included both shoreline and mid-channel

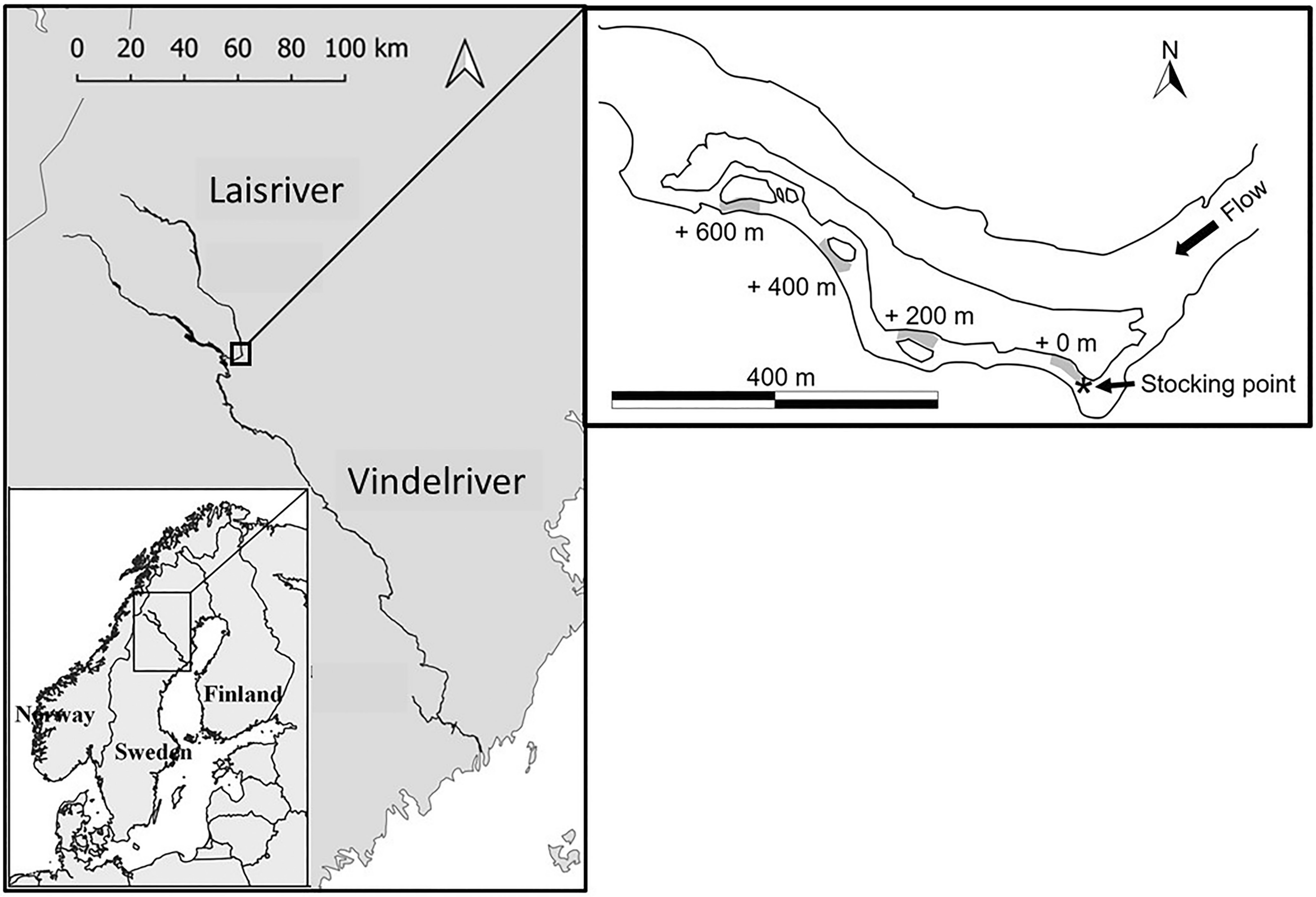

FIGURE 1 Geographic location of the Laisriver in northern Sweden and location of the study area where brown trout eggs were stocked (indicated by an *) and young brown trout were sampled by electrofishing (gray-shaded polygons) in August 2016–2019. Distance downstream from the stocking point is indicated by plus values (+).

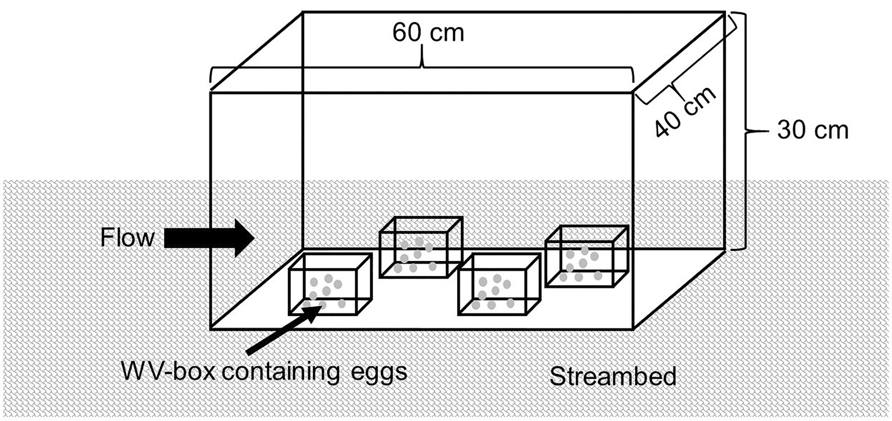

FIGURE 2 Schematic drawing of Whitlock Vibert (WV) boxes used to stock brown trout eggs in the Laisriver, Sweden, in August 2016–2019. The gravel that was loaded into the perforated plastic crate is not shown in the figure.

habitat, for a total area of 2294 m^2. Electrofishing was a single pass (Bohlin et al., 1989) with a generator-powered control unit (Lugab, Lulea, Sweden) that produced constant direct current of 800 V. A regional equipment-specific catchability of 0.35 for YOY trout was used to estimate density. To control for variability in maximum discharge between emergence and sampling, the measurements of discharge from a nearby flow gauging station were collected from July 1st to August 31st. To compare relative stocking success between stocking levels (30,000 and 60,000 eggs), annual relative survival of egg-to-YOY trout was calculated as the annual mean YOY density of four electrofishing sites, divided by the number of eggs stocked.

2.4 | Statistical analyses

YOY trout density and body length were modeled as functions (dependent variables) of numbers of stocked eggs and downstream distance from the stocking point in two mixed models. Fixed factors, interactions, covariates, and random factors were identical in the two models. Fixed factors were stocked egg numbers (30,000 or 60,000 eggs) and downstream distance from the stocking point (+0, +200, +400, or +600 m). The interaction was the product of egg number and distance downstream from the stocking point. In case of non-significant interactions, only the main effects were later compared. The covariate was the maximum discharge between emergence and sampling, and year was a random factor. In case of non-significant interactions, only the main effects were compared. Tukey's post-hoc comparisons were used to compare effects at a $p \leq 0.05$ significance. Two years at each stocking level prevented testing for differences in relative survival of egg-to-YOY trout. Finally, to test if YOY trout density was related to mean body length at different sites, partial Pearson correlations were used, after controlling for year. Statistical analysis was conducted using PROC MIXED and PROC CORR in SAS (SAS 9.4, SAS Institute Inc., Cary, NC, USA).

3 | RESULTS

Inspection of the crates revealed no movement, damage to WV boxes, sediment accumulation, or unhatched eggs. Discharge ranged from 23 to 226 m^3/s between the first of July and sampling at the end of August (Figure 3). With the exception of a spate in mid-July in 2017, no extreme flood events occurred during the study.

Total brown trout collected by electrofishing included 780 YOY and 82 ≥ age-1+ at the four sites. Other species were only 1.8% of total fish caught across all sampling events, including nine juvenile salmon, seven juvenile grayling, seven juvenile burbot, one juvenile perch, one juvenile roach, and one juvenile pike. Mean YOY density was 18.4 trout/100 m^2 at the 30,000 egg stocking level and 29.3 trout/100 m^2 at the 60,000 egg stocking level (sites and years pooled). Mean age-1+ density was 1.5 trout/100 m^2 at the 30,000 egg stocking level and 2.5 trout/100 m^2 at the 60,000 egg stocking level (sites and years pooled). Relative survival of egg-to-YOY trout was 0.0004 in 2017 and 0.0005 in 2016, when stocked with 60,000 eggs, and 0.0005 in 2018 and 0.0007 in 2019, when stocked with 30,000 eggs.

For YOY trout density, the interaction between egg stocking level and distance from the stocking point was significant ($F=12.05$, $df_1=3$, $df_2=6$, $p=0.006$), so the analysis was split between stocking levels. At a stocking level of 30,000 eggs, YOY trout density did not differ significantly among sites at different distances from the stocking point ($F=1.42$, $df_1=3$, $df_2=6$, $p=0.327$). In contrast, at a stocking level of 60,000, YOY trout density increased significantly with increasing distance from the stocking point ($F=23.78$, $df_1=3$, $df_2=6$, $p=0.001$) (Figure 4). Maximum discharge was not significantly related to YOY trout density ($F=0.50$, $df_1=1$, $df_2=1$, $p=0.609$).

Neither maximum discharge ($F=0.51$, $df_1=1$, $df_2=1$, $p=0.606$) nor the interaction between egg number and distance from the stocking point ($F=0.36$, $df_1=3$, $df_2=6$, $p=0.782$) were significantly related to differences in YOY trout body length and sampling sites. Body length was significantly related downstream distance from the stocking point ($F=16.01$, $df_1=3$, $df_2=6$, $p=0.003$). YOY trout were slightly longer at 0 m (56.2 ± 4.6 mm; mean ± SE) and 200 m (58.3 ± 3.9 mm) downstream from the stocking point than at 400 m (50.6 ± 4.1 mm) and 600 m (52.0 ± 3.1 mm) downstream from the stocking point. YOY mean length differed significantly between 0 and 400 m, 200 and 400 m, and 200 and 600 m distances downstream from the stocking point (Figure 5). Egg numbers were not significantly correlated with YOY trout body length ($F=0.30$, $df_1=1$, $df_2=1$, $p=0.682$). YOY trout density was not significantly correlated with YOY trout body length ($r=-0.52$, $df=11$, $p=0.070$), after adjusting for the year of sampling.

4 | DISCUSSION

Our results suggested that egg stocking density increased dispersal of YOY trout from the stocking site, which was consistent with previous studies of brown trout and Atlantic salmon (Einum & Nislow, 2005; Einum et al., 2011; Eisenhauer et al., 2020; Elliott, 1984, 1986, 1994; Milner et al., 2003) and chinook salmon (*Oncorynchus tschwytscha*; Conley et al., 2020). In contrast, we found that YOY trout length was not significantly correlated with YOY trout density,

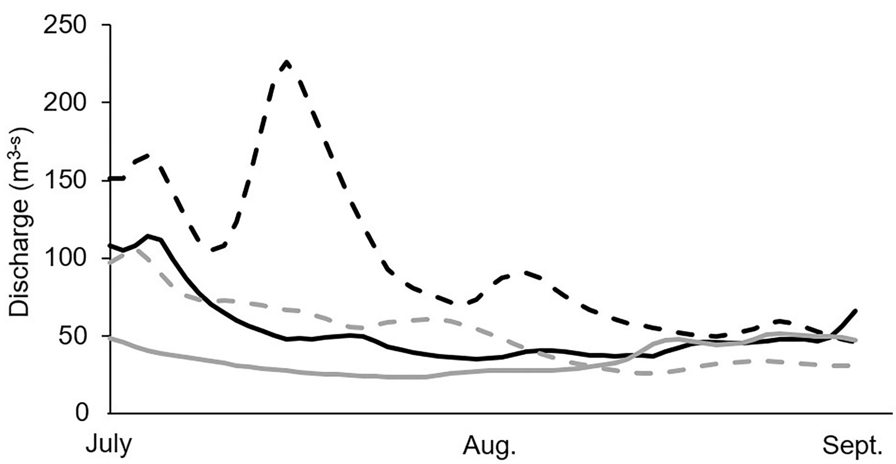

FIGURE 3 Discharge (m^3/s) in the Laisriver, Sweden, during July–August, 2016 (solid black line), 2017 (broken black line), 2018 (solid gray line), and 2019 (broken gray line).

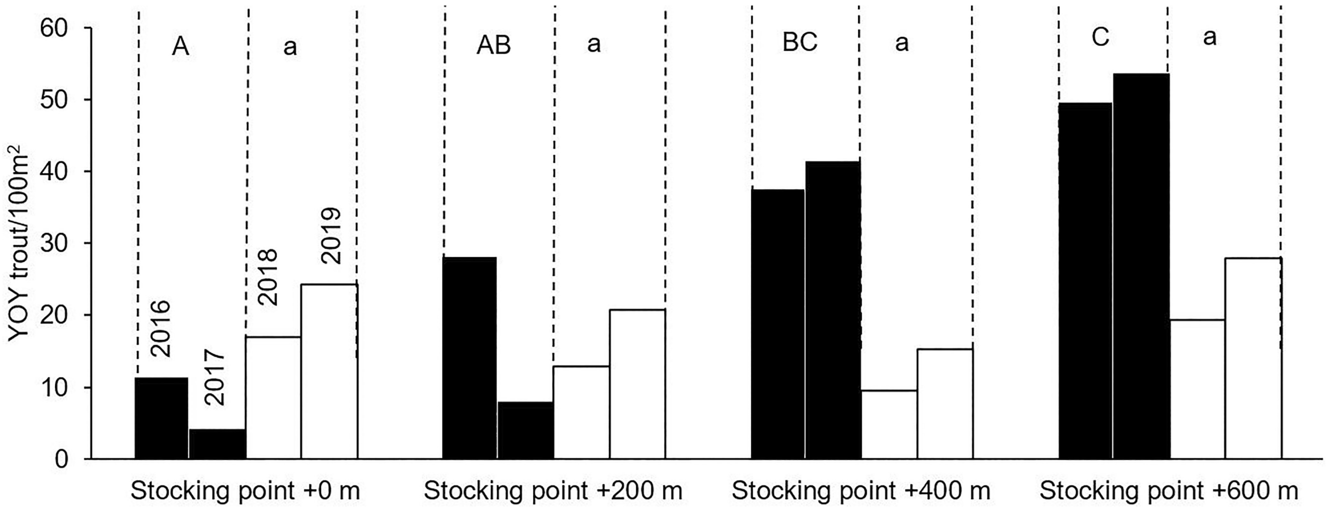

FIGURE 4 Relative abundance (number/100 m^2) of young-of-year (YOY) brown trout caught by electrofishing at four sites located 0, 200, 400, and 600 m downstream of the stocking site in the Laisriver, Sweden, in August 2016–2019. Black bars indicate years when 60,000 trout eggs were stocked, and white bars indicate years when 30,000 trout eggs were stocked. Contrasting letters, upper and lower case, indicate significant differences between sites (upper case for years of 60,000 stocked trout eggs and lower case for years of 30,000 stocked trout eggs). Bars that share letters are not significantly different from each other.

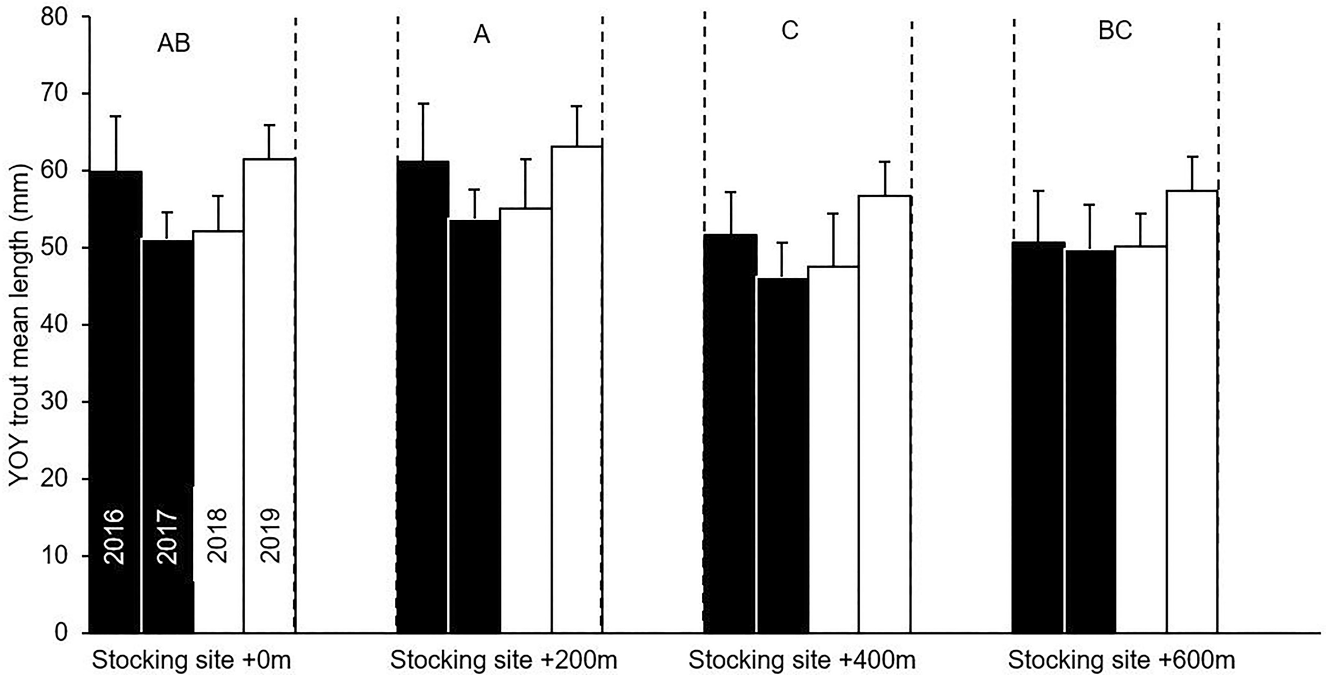

FIGURE 5 Mean total length (mm) of young-of-year (YOY) brown trout (+SE) at four electrofishing sites located 0, 200, 400, and 600 m downstream of the stocking site in the Laisriver, Sweden, in August 2016–2019. Black bars indicate years when 60,000 trout eggs were stocked, and white bars indicate years when 30,000 trout eggs were stocked. Groups of bars that share letters are not significantly different from each other (stocking levels pooled).

although the negative sign of the correlation aligned with earlier studies of brown trout and Atlantic salmon fry (Einum et al., 2008, 2011; Eisenhauer et al., 2020; Elliott, 1984). Although we found significant differences in body length between some sampling sites downstream from the stocking location, YOY trout length did not consistently increase or decrease with distance from the stocking site, which could be a result of fine-scale differences in feeding conditions and habitat quality rather than competition (given that density should have been highest nearest to the stocking location). For instance, inconsistent variability in body length with distance from the stocking location in our study could be a result of the large quantity of available habitat downstream of the stocking point and success of YOY trout to find suitable habitat after emergence. In a system with limited suitable habitat, high stocking levels could result in redistribution of YOY to suboptimal locations that result in poor growth or low survival and lower egg to YOY relative survival. Collectively, our results suggest that stocking programs should incorporate a monitoring program that begins at low egg density with the intent to increase or reduce egg density, if necessary, to reduce negative impacts and maximize use of available resources.

Variability in maximum discharge was not significantly related to density or body length of YOY trout in our study, although the distribution, survival, and growth of salmonid fry can be affected by discharge because of their sedentary behavior immediately after emergence (Jensen & Johnsen, 1999; Quinn, 2018). For example, year-class strength of brown trout and Atlantic salmon was negatively related to peak discharge during the alevin stage, perhaps because of downstream displacement, although flow conditions after the alevin stage did not significantly affect year class strength, perhaps due to improved swimming ability when alevins reached the YOY fry stage (Jensen & Johnsen, 1999). In our study, the spate that occurred about 2 weeks after emergence in mid-July 2017 likely had limited influence on survival or body length. Furthermore, variation in maximum discharge may have been less than the magnitude necessary to significantly affect density and body length or to allow us to detect the effect, especially considering the low gradient of our study stream. Dispersal of trout following emergence from stocking locations is likely complex, so future research is needed to understand how discharge and other environmental factors affect post-stocking survival and dispersal across a range of environmental conditions and habitat types.

Our findings revealed important understanding of the distribution and size of YOY trout in relation to egg stocking density, but may have been affected by important limitations of the study design. First, some YOY trout we collected may have been naturally produced, because wild trout occur in the river, although effects of naturally produced YOY trout were likely minimal due to their low abundance (Jonsson et al., 1999; Swedish Electrofishing Register—SERS, 2022). Second, patterns we observed could have been a result of differences in YOY trout habitat suitability among sites not measured in our study, which could have had a prevailing effect on our results. However, potential effects on YOY trout density caused by differences in habitat suitability should have been identical between stocking levels as the habitat was not altered during the study period. This suggests that the number of eggs stocked was a more important predictor of YOY density than differences in habitat suitability between sites. Third, the presence of older trout or other species not included in our analysis could have influenced our results through intraspecific or interspecific competition (Elliott, 1994; Kaspersson et al., 2012), although density of age-1+ trout and other species was much lower compared to YOY trout density, so effects of older trout and other species were likely minimal (e.g., Hagelin & Bergman, 2021; Stradmeyer et al., 2008). Future studies of egg stocking density should include multiple study sites in a BACI design and separate stocked from wild fish using tags.

Given the existing anthropogenic stress on freshwater ecosystems and the associated decline in fish abundance (Young et al., 2016), egg stocking has become increasingly important as a potentially cost-effective management strategy to restore fish populations (Marsh et al., 2005). If stocked fish can be assured to not negatively affect genetic diversity and fitness of existing populations (e.g., Christie et al., 2012), egg stocking can circumvent negative effects of rearing fish in hatcheries prior to stocking (Naslund, 2021). Although results of our study and prior research provide valuable insights for egg stocking programs, additional research is needed on more waters and species over large distances (i.e., thousands of meters) to more fully understand the outcome of stocking and to generalize results.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on reasonable request from the corresponding author.

ETHICS STATEMENT

This study was conducted under the ethic approval A1/2016.

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