The relation between age-0 rainbow trout (*Oncorhynchus mykiss*) abundance and winter discharge in a regulated river

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Abstract: We identified and experimentally tested a discharge–abundance relation that predicted, based on the mean river discharge in the second half of winter (15 January – 31 March), the spring abundance of age-0 rainbow trout (*Oncorhynchus mykiss*) in a section of the Henrys Fork of the Snake River, Idaho, with complex bank habitat. We also considered a competing hypothesis in which autumn abundance determined spring abundance. We established that large abundances of age-0 trout were present in autumn (34 000 – 81 000) and lower abundances remained in spring (8000 – 15 000). Winter loss of age-0 trout was initiated in January. Spring abundance in 1996–1998 was related to autumn abundance ($r^2 > 0.99$) and mean discharge in the second half of winter (17.1–22.8 $m^3 \cdot s^{-1}$; $r^2 > 0.99$) but not mean discharge in the first half of winter (15.1–21.1 $m^3 \cdot s^{-1}$; $r^2 = 0.11$). We experimentally maintained a high discharge (20–21 $m^3 \cdot s^{-1}$) in the second half of winter in 1999 to test model predictions. Autumn abundance failed to predict spring abundance (observed = 11 109; predicted = 6822; 95% prediction interval = 4669–8975). However, the discharge–abundance model accurately predicted spring abundance (predicted = 11 980; 95% prediction interval = 10 728 – 13 231). Higher discharge in the second half of winter may have provided more bank habitat at a critical time for survival.

Résumé : Nous avons découvert et vérifié expérimentalement une relation entre le débit et l'abondance qui prédit, d'après le débit moyen de la rivière durant la seconde moitié de l'hiver (15 janvier – 31 mars), l'abondance des truites arc-en-ciel (*Oncorhynchus mykiss*) d'âge 0 au printemps dans un secteur à habitats de berge complexes dans le tributaire the Henrys Fork de la rivière Snake en Idaho. Nous avons aussi examiné une hypothèse de rechange qui relie l'abondance au printemps à l'abondance à l'automne. Les abondances de truites d'âge 0 sont fortes à l'automne (34 000 – 81 000) et plus faibles au printemps (8000 – 15 000). La perte de truites d'âge 0 commence en janvier. L'abondance au printemps en 1996–1998 était fonction de l'abondance à l'automne ($r^2 > 0,99$) et du débit moyen dans la seconde moitié (17,1–22,8 $m^3 \cdot s^{-1}$; $r^2 > 0,99$), mais pas dans la première moitié (15,1–21,1 $m^3 \cdot s^{-1}$; $r^2 = 0,11$) de l'hiver. Nous avons maintenu expérimentalement un débit élevé (20–21 $m^3 \cdot s^{-1}$) pendant la seconde moitié de l'hiver en 1999 pour vérifier les prédictions du modèle. L'abondance en automne n'a pas permis de prédire l'abondance au printemps (observée = 11 109; prédite = 6822; intervalle de prédiction 95 % = 4669–8975). En revanche, le modèle basé sur le débit et l'abondance a prédit de façon précise l'abondance au printemps (prédite = 11 980; intervalle de prédiction 95 % = 10 728 – 13 231). Le fort débit durant la seconde moitié de l'hiver accroît probablement les habitats de berge à un moment critique pour la survie.

[Traduit par la Rédaction]

Introduction

In a study of rainbow trout (*Oncorhynchus mykiss*) recruitment in the Henrys Fork of the Snake River, Idaho, Mitro and Zale (2002*a*) investigated when apparent mortality of age-0 trout occurred seasonally and where recruitment occurred in a 25-km reach of the river system. They found evidence that availability of winter habitat limited rainbow trout recruitment in the Henrys Fork. Most river sections in the Henrys Fork had only simple bank habitat and did not support age-0 rainbow trout throughout winter (Mitro and Zale 2002*a*). The winter habitat that supported age-0 trout was complex bank habitat, and age-0 trout survived throughout winter only where such habitat was present, primarily in the Box Canyon

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river section. Other studies have identified salmonid recruitment limitation in association with limited winter habitat availability (Elliott 1994; Cunjak 1996; Cunjak et al. 1998).

Interannual variation in first-winter apparent survival in the Box Canyon river section of the Henrys Fork was relatively low (18–23%; Mitro and Zale 2002*a*) compared with interannual variation in winter survival of salmonids in other river systems (Seelbach 1993; Ward and Slaney 1993; Quinn and Peterson 1996). However, there was interannual variability in recruitment from Box Canyon. Understanding the mechanism behind any variation in recruitment is important to fisheries managers because such knowledge may help guide management options that may improve a fishery.

We formulated and tested two hypotheses regarding what factors influenced or determined annual differences in spring abundance of age-0 rainbow trout in the Box Canyon section of the Henrys Fork. One hypothesis was that abundance in spring was a function of abundance in the previous summer or autumn, i.e., the more age-0 trout entering a winter, the more that survive. The second hypothesis was that abundance in spring was a function of river discharge, i.e., different discharge levels differentially inundated complex bank habitat in Box Canyon, thereby influencing the availability of winter habitat and the abundance of age-0 trout in spring. We investigated these hypotheses using data from Mitro and Zale (2002*a*) and tested the hypotheses using additional data collected in winter 1998–1999 when we manipulated discharge from Island Park Dam into the river.

Materials and methods

Study area

The Henrys Fork of the Snake River at Island Park Dam (44°24′59′′ latitude, 111°23′41′′ longitude) is at an elevation of 1897 m and has a drainage area of 1246 km^2. The mean annual discharge through Island Park Dam from October 1994 through April 1999 was 23 $m^3 \cdot s^{-1}$ (range 5.9–78.4 $m^3 \cdot s^{-1}$). The Buffalo River enters the Henrys Fork about 0.25 km downstream of Island Park Dam. The Buffalo River is a spring-fed river that has a relatively constant discharge of about 6 $m^3 \cdot s^{-1}$.

Box Canyon begins at the confluence of the Henrys Fork and the Buffalo River and is 4 km long with a mean width of 70 m. (See fig. 1 in Mitro and Zale (2002*a*) for a map of the study area.) Box Canyon is a relatively high gradient area (0.45%) with a cobble–boulder substrate and sloping banks (20–45°) strewn with boulders, large cobbles, and large woody debris. This river section has complex bank habitat consisting of rocks and woody debris; there are few macrophytes across the channel. Most successful overwintering of age-0 rainbow trout occurs in this section (Mitro and Zale 2002*a*). Box Canyon was divided into two sections for the purpose of estimating abundance: upper Box Canyon (1.5 km) and lower Box Canyon (2.5 km). Upper Box Canyon is characterized by areas of rapids, depths exceeding 1 m, and large uneven substrate. Lower Box Canyon is wider and the depth is usually less than 1 m. Generally, no ice forms in Box Canyon. Winter water temperature is moderated by hypolimnetic releases from Island Park Reservoir (2–4°C) and water from the spring-fed Buffalo River (1–6°C).

Last Chance is immediately downstream of Box Canyon and is 4 km long with a mean width of 95 m. Last Chance is a moderate gradient area (0.3%) with a cobble substrate and vertical consolidated sand and silt banks held together by wet meadow grasses and sedges. The channel depth is usually less than 1 m and there are extensive macrophyte beds across the channel throughout the river section. Bank habitat in Last Chance is simple, lacking the rocks and woody debris prevalent upstream in Box Canyon. Macrophyte beds decrease through winter (but are not eliminated) because of senescence and grazing by trumpeter swans (*Cygnus buccinator*) and other waterfowl (Van Kirk and Martin 2000). Generally no ice forms in Last Chance and none was observed during this study.

Age-0 rainbow trout abundance and discharge

We estimated the abundance of age-0 trout in autumn (October) and spring (May) using mark–recapture and removal methodologies (Mitro and Zale 2000, 2002*a*, 2002*b*). We sampled two areas in autumn in lower Box Canyon (1995–1998) using mark–recapture to estimate abundance (Mitro and Zale 2002*b*). Mark–recapture sample areas were 100 m long and extended from bank to bank. We used the same sample areas each year. We collected age-0 rainbow trout by wading with boat-mounted electrofishing gear (continuous DC, 250 V) from one bank to the other along eight transects per sample area, perpendicular to the flow. Each sample area was sampled either 4 or 5 days, generally every other day. Trout were marked with partial fin clips and a different fin clip was used on each day. Sample areas were considered closed such that no significant losses or additions occurred during the sampling period (Mitro and Zale 2002*b*). Mark–recapture data were analyzed using the Chao M_t estimator in program CAPTURE (Chao 1989; Rexstad and Burnham 1991; Mitro and Zale 2002*b*). Mean abundance estimates for sample areas were extrapolated to areas not sampled to estimate the total abundance of age-0 trout in each river section. Confidence intervals (95%) for estimates of total abundance included within-sample area, among-sample area, and extrapolation error. See Mitro and Zale (2002*a*, 2002*b*) for further details on the sampling procedure and data analysis.

We sampled multiple 10- to 15-m bank units along the banks in upper Box Canyon in autumn (1995–1998) and throughout Box Canyon in spring (1996–1999) using removal methodologies to estimate abundance (Mitro and Zale 2000, 2002*a*). Bank units were sampled primarily by three-pass removal (about 10% by single-pass removal) by wading with a handheld electrode (continuous DC, 250 V). We sampled seven bank units in upper Box Canyon in autumn in 1995 and 10 bank units in 1996–1998. We sampled 20 bank units in Box Canyon in spring in 1996 and 50 bank units in 1997–1999. Three-pass removal data were analyzed using the Zippin maximum likelihood removal estimator (Zippin 1956; Otis et al. 1978; Rexstad and Burnham 1991). Single-pass removal data were analyzed using a mean capture probability model calibrated for the Henrys Fork (Mitro and Zale 2000). Mean abundance estimates for bank units were extrapolated to areas not sampled to estimate the total abundance of age-0 trout in each river section.

We identified the temporal pattern of overwinter loss of age-0 rainbow trout from Last Chance using a catch-per-unit-effort methodology. Last Chance was used as a surrogate for Box Canyon because Box Canyon is inaccessible during winter. We assumed that, in general, temporal shifts in habitat use and abundance would be similar in the two sections. Smith and Griffith (1994), in a study of first-year survival of caged age-0 rainbow trout in the Box Canyon and Last Chance sections of the Henrys Fork, found that the timing of mortality is independent of river location. Ten random bank-to-bank transects were sampled by electrofishing (continuous DC, 250 V) once a month from November through April in winters 1996–1997, 1997–1998, and 1998–1999.

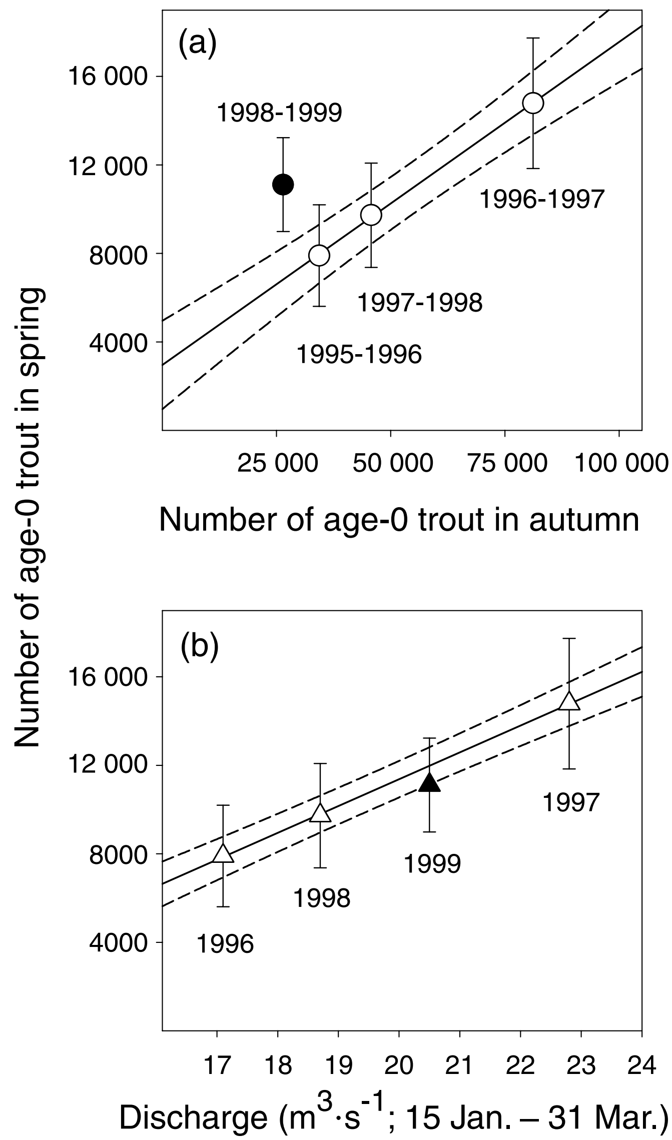
We used simple linear regression to quantify the relation between autumn and spring age-0 rainbow trout abundance and between discharge during the first (1 November – 14 January) and second (15 January – 31 March) halves of winter and spring age-0 trout abundance using data from the first 3 years of the study. Discharge data for the Henrys Fork were obtained for each winter from the United States Geological Survey gauging station near Island Park Dam (Station 13042500). Discharge during the second half of winter 1998–1999 (the 4th year of the study) was maintained at a relatively high level (20–21 $m^3 \cdot s^{-1}$) to experimentally test the discharge–abundance model. Each model was tested by comparing the number of age-0 rainbow trout in Box Canyon in spring 1999 to the model prediction.

Results

Large abundances of age-0 rainbow trout were present in Box Canyon in autumn in each year of the study: 34 353 in 1995 (95% confidence interval (CI) = 29 781 – 38 927), 81 165 in 1996 (95% CI = 61 858 – 100 471), and 45 723 in 1997 (95% CI = 37 335 – 54 110). Considerable losses (attributable to mortality or movement) of age-0 trout occurred during each winter. The temporal pattern of age-0 trout loss as measured in Last Chance was consistent among years. There was no evidence of loss in November or December, the loss was initiated between December and January and continued through March, and numbers then increased in April. The total catch per 10 transects by month was 139, 146, 64, 28, 15, and 33 for November 1996 – April 1997 and 148, 151, 72, 7, 4, and 55 for November 1997 – April 1998. The abundance of age-0 rainbow trout in Box Canyon in spring was 7903 in 1996 (95% CI = 5608 – 10 197), 14 788 in 1997 (95% CI = 11 835 – 17 740), and 9730 in 1998 (95% CI = 7372 – 12 082).

There was a positive relation between the abundance of age-0 rainbow trout in autumn and spring (Fig.1*a*; intercept = 2958 and slope = 0.146; $r^2 > 0.99$) and a positive relation between discharge in the second half of winter and spring age-0 trout abundance (Fig. 1*b*; intercept = –12 887 and slope = 1213; $r^2 > 0.99$) for the first 3 years of this study. Winter discharge varied within and among years. Mean (and minimum) discharge in the first half of winter (1 November – 14 January) was 15.6 (14.7) $m^3 \cdot s^{-1}$ in 1995–1996, 15.1 (13.6) $m^3 \cdot s^{-1}$ in 1996–1997, and 21.1 (18.4) $m^3 \cdot s^{-1}$ in 1997–1998. In the second half of winter (15 January – 31 March), mean (and minimum) discharge was 17.1 (14.2) $m^3 \cdot s^{-1}$ in 1996, 22.8 (17.7) $m^3 \cdot s^{-1}$ in 1997, and 18.7 (15.8) $m^3 \cdot s^{-1}$ in 1998. The number of age-0 trout in Box Canyon in spring was positively related to discharge in the second half of winter ($r^2 > 0.99$; Fig. 1*b*) but not the first half of winter ($r^2 = 0.11$).

Fig. 1. Relation between (*a*) age-0 rainbow trout (*Oncorhynchus mykiss*) abundance in autumn and (*b*) mean discharge ($m^3 \cdot s^{-1}$) from Island Park Dam between 15 January and 31 March and abundance of age-0 trout in spring in Box Canyon. Each model was fitted to data from 1996–1998 (open symbols) and tested with an observation from 1999 (solid symbol). Solid line represents the linear regression line; broken lines represent the 95% prediction intervals; error bars represent the 95% confidence intervals.



Discharge was experimentally maintained at a relatively high mean level during the second half of winter 1998–1999 at 20.5 $m^3 \cdot s^{-1}$ (minimum = 17.2 $m^3 \cdot s^{-1}$). Age-0 rainbow trout abundance in Box Canyon and the temporal pattern of loss as measured in Last Chance during that winter were consistent with observations from the previous three winters (Fig. 1*b*). A large abundance of age-0 rainbow trout was in Box Canyon in autumn 1998: 26 460 (95% CI = 18 654 – 34 266). The total catch per 10 transects in Last Chance by month was 132, 105, 52, 17, 12, and 28 for November 1998 – April 1999. In spring 1999, the abundance of age-0 trout in Box Canyon was 11 109 (95% CI = 8 986 –13 233).

The model relating abundance in autumn and spring failed to predict the number of age-0 rainbow trout in Box Canyon in spring 1999. This model predicted that with 26 460 age-0 trout present in autumn, there would be 6822 age-0 trout in spring. This prediction was about 39% less than the empirical estimate of abundance in spring; the 95% prediction interval of 4669–8975 failed to capture the empirical estimate of 11 109.

The discharge–abundance model accurately predicted the number of age-0 rainbow trout in Box Canyon in spring 1999 based on the mean discharge during the second half of winter. The model predicted that at a mean discharge of 20.5 $m^3 \cdot s^{-1}$ observed for 15 January – 31 March 1999, there would remain 11 980 age-0 trout in Box Canyon in spring. This prediction was about 8% greater than the empirical estimate of abundance in spring; the empirical estimate of 11 109 was within the 95% prediction interval of 10 728 – 13 231.

Discussion

We tested whether autumn abundance or discharge in the second half of winter was a better predictor of spring abundance of age-0 rainbow trout in the Box Canyon section of the Henrys Fork. Spring abundance of age-0 trout was related to both autumn abundance and discharge in the first 3 years of the study. However, in testing the models with additional data from 1998–1999, only the discharge–abundance model accurately predicted spring age-0 trout abundance. Mitro and Zale (2002*a*) showed that complex bank habitat could be limiting to age-0 rainbow trout during winter in a sense that trout were present in spring only where such habitat was present and not where it was absent. This study showed that varying discharge, and hence the amount of winter habitat, at a time when habitat availability was critical to survival influenced spring abundance.

The number of age-0 rainbow trout in Box Canyon in spring was positively related to discharge during the second half of winter; there was no relation between spring abundance and discharge during the first half of winter. The catch-per-unit-effort data from Last Chance indicated that the loss of age-0 trout, which likely included movement, occurred in midwinter. Higher discharge in the second half of winter may therefore have provided more bank habitat in Box Canyon at a critical time for survival. Bank habitat that provides interstitial space for shelter is critical to the winter survival of age-0 river salmonids (Griffith and Smith 1993; Cunjak 1996; Mäki-Petäys et al. 1997). Trout from other river sections may move upstream to find available bank habitat (Mitro and Zale 2002*a*) as macrophytes become unsuitable for winter survival and trout begin to move to bank habitat (Griffith and Smith 1995).

The positive relation between age-0 trout abundance in Box Canyon in autumn and spring in the first 3 years of this study suggested that perhaps discharge was not such an important variable. However, the number of age-0 trout in autumn 1998 was lower than in any other year of this study and the number of age-0 trout in spring 1999 was the second largest. The failure of autumn abundance to predict spring abundance suggested that discharge during the second half of winter, that is, habitat availability, rather than production was the driving factor in determining spring abundance of age-0 rainbow trout.

An increase in the number of age-0 rainbow trout captured in 10 random transects in Last Chance occurred in April each year. This increase occurred among trout using center channel habitat (Mitro and Zale 2002*a*) and suggested that age-0 trout were moving back into Last Chance at the end of winter. These trout were probably not concealed in the substrate earlier in the winter because the substrate in Last Chance is highly embedded. The movement of age-0 trout back to center channel habitat in April suggests that concealment substrate is no longer critical at that time.

A positive relation between the mean discharge in February and the survival of age-0 Atlantic salmon (*Salmo salar*) was observed in New Brunswick and Newfoundland (Gibson and Meyers 1988). A positive relation was also found between winter discharge and age-0 Atlantic salmon survival in Catamaran Brook, N.B. (Cunjak et al. 1998). Unlike these streams, the Henrys Fork is a regulated river. Discharge can be controlled and used as a management tool to improve natural recruitment of rainbow trout in the Henrys Fork. Applicability of our findings elsewhere is unknown but deserves evaluation, particularly in other tailwater systems and perhaps also streams subjected to artificial reductions in discharge during winter such as is associated with snowmaking at ski areas.

If discharge is increased to support age-0 trout during the second half of winter in the Henrys Fork, any increase in discharge should precede or coincide with the midwinter loss of age-0 trout. In this study, with mean discharge in the first half of winter ranging from 15.1 to 21.1 $m^3 \cdot s^{-1}$, the loss of age-0 trout was initiated between December and January. However, when discharge was relatively low in winter 1994–1995 (mean 7.2 $m^3 \cdot s^{-1}$), the loss was initiated between November and December (Mitro 1999). Discharge and the temporal pattern of age-0 trout loss should therefore be monitored to assist decision-making about discharge regulation.

We recommend a high level of discharge (>20 $m^3 \cdot s^{-1}$) during the second half of winter to improve the recruitment of age-0 rainbow trout in the Henrys Fork. The water stored in Island Park Reservoir is currently managed for multiple uses, including power production and irrigation. In past winters, excess water has been released from the reservoir in early winter in anticipation of a large snowpack. Delay of such releases until late winter when age-0 rainbow trout move from midstream macrophytes to bank cover would enhance spring abundances of age-0 trout in Box Canyon. We also recommend continued testing of the discharge–abundance relation, particularly beyond the bounds of discharge encountered in this study.

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