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NOTES

Utility of Depth and Velocity Preferences for Predicting Steelhead Parr Distribution at Different Flows

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Abstract.—We tested an assumption of the instream flow incremental methodology that depth and velocity preferences are independent of streamflows. We had previously developed depth and velocity preferences (P[*d*] and P[*v*]) for juvenile (parr) steelhead *Oncorhynchus mykiss* at 0.86 m^3/s in Morse Creek, Washington, and found parr distributed in microhabitats with higher combined depth–velocity preference (P[*dv*] = P[*d*] × P[*v*]) at a similar flow (0.69 m^3/s). In the present study, we evaluated the relationship between fish distribution and combined depth–velocity preference using an independent data set from a higher flow (2.41 m^3/s) in the adjacent stream segment. Most steelhead parr were distributed in microhabitats with high P[*dv*], consistent with distribution at 0.69 m^3/s and significantly different than expected if fish distribution were independent of habitat preference (chi-square, $P < 0.02$). These results suggest that depth and velocity preferences are independent of flow.

The instream flow incremental methodology (IFIM) (Stalnaker 1980; Bovee 1982) is widely used for estimating fish needs in water allocation (Loar et al. 1985; Reiser et al. 1989), but it has also been criticized (Mathur et al. 1985; Scott and Shirvell 1987). A central part of IFIM is the physical habitat simulation system (PHABSIM), which evaluates hydraulic conditions at different flows in relation to fish preferences for depth, velocity, and substrate or cover.

Among the critical assumptions of IFIM are that fish selectively occupy preferred habitat, determined in part by depth and velocity preferences (Bovee and Cochnauer 1977; Stalnaker 1980; Bovee 1982, 1986; Milhous et al. 1984), and that fish preferences for depth and velocity remain constant during changing flow. Distribution of juvenile (parr) steelhead *Oncorhynchus mykiss* is related to depth and velocity preference, as assumed in PHABSIM (Beecher et al. 1993). However, Shirvell (1990) observed that steelhead parr used different velocities at different flows, raising the possibility that steelhead parr change their microhabitat preferences as flow changes, even within a season. If their preferences changed within a season, an assumption of PHABSIM would be violated.

To test whether depth and velocity preference change with flow, we compared distribution of steelhead parr within a stream segment during July snowmelt to distribution of preferred depths and velocities. Depth and velocity preferences were measured and verified at lower flows in September (Beecher et al. 1993). In the present study, we again verified the preferences at a higher flow to validate the assumption of independence of depth and velocity preferences from flow. The null hypothesis was that fish distribution is independent of depth and velocity preferences determined at a different flow.

Study Area

Our study site was about 3 km upstream from the mouth of Morse Creek near Port Angeles on the north slope of the Olympic Mountains, Washington (Beecher et al. 1993). Morse Creek is a small, steep stream (mean annual flow 3.58 m^3/s, drainage area about 146 km^2, mainstem length 26.1 km, average gradient >6%) that flows into the Strait of Juan de Fuca within sight of its source in alpine snowfields. Snowmelt flows peak in June (median June flow, 5.5 m^3/s) and continues through July. Flows are low from late August through October, depending upon onset of fall rains, with lowest monthly median flow of 1.0 m^3/s in September. Highest flows occur during heavy rains during late fall and early winter (November–January; Williams et al. 1985). Flow at our study site on the date of preference curve development (3–4 September 1987) was 0.86 m^3/s and stream width averaged 12.6 m (range, 7.4–25.2 m). On the date of our distribution test (18 July 1991), flow was 2.41 m^3/s, and stream width averaged 16.2 m (range, 12.4–23.2 m), compared to a flow of 0.69 m^3/s when our previous distribution test was conducted (Beecher et al. 1993).

The study site contained a chute, pool, run, and riffle immediately upstream of the segment used for habitat preference curve development. The two

TABLE 1.—Depth and velocity preferences for 104 steelhead parr in Morse Creek, September 1987, at a flow of 0.86 m^3/s (from Beecher et al. 1993).

Depth		Velocity	
Interval (m)	Preference P[*d*]	Interval (cm/s)	Preference P[*v*]
<0.15	0.00	<3.0	0.18
0.15–0.18	0.04	3.0–8.8	0.36
0.18–0.24	0.08	9.1–11.9	0.34
0.24–0.27	0.35	12.2–14.9	0.09
0.27–0.30	0.17	15.2–21.0	0.55
0.30–0.33	0.53	21.3–27.1	1.00
0.34–0.39	0.22	27.4–33.2	0.96
0.40–0.48	0.42	33.5–39.3	0.67
0.49–0.76	0.59	39.6–45.4	0.81
>0.76	1.00	45.7–51.5	0.88
		51.8–60.7	0.65
		61.0–106.4	0.62
		>106.4	0.25

segments were similar. In the test segment, the left bank was cutbank and the right bank was a gravel bar. Substrate was relatively uniform with poorly sorted cobble and gravel throughout the study reach, but some boulders and bedrock were present. In our study reach, cobble provided the main cover. Instream woody debris was scarce in this segment of Morse Creek. The pool did not exceed about 1.5 m depth during our sampling.

The stream is inhabited by steelhead, anadromous cutthroat trout *Oncorhynchus clarki,* chinook salmon *O. tshawytscha,* coho salmon *O. kisutch,* chum salmon *O. keta,* pink salmon *O. gorbuscha,* and Dolly Varden *Salvelinus malma,* as well as unidentified sculpins *Cottus* spp. Steelhead and coho salmon are numerically dominant as rearing salmonid fishes, with both species in pools and steelhead predominating in riffles and chutes. In mid-July 1991 (during this study) apparent abundance of steelhead parr was much lower than in September of three earlier years, perhaps because of the low temperature (10°C) of meltwater in July.

Methods

In September 1987 at a flow of 0.86 m^3/s, we developed depth and velocity preferences (P[*d*] and P[*v*]) from 104 observations of steelhead parr (Table 1; Beecher et al. 1993). We calculated these preferences by scaling ratios of observed use to expected use based on availability (Obs/Exp) for different intervals of depth or velocity. These ratios were scaled so that the maximum values of P[*d*] and P[*v*] were 1.0 for the most preferred depths and velocities.

In the present study, we tested the accuracy of these preferences for predicting steelhead parr distribution at a given flow. On 18 July 1991 at a flow of 2.41 m^3/s, we recorded steelhead parr distribution and microhabitat use and availability along 14 transects across an adjacent segment of Morse Creek. Transects were placed at 4.6-m intervals along the stream through one pool–riffle sequence immediately upstream of the preference curve development segment. At each transect, we visually identified the left bank (opposite) end; then one of us entered the water downstream from the left end of the transect, snorkeled slowly up to the end of the transect, and then snorkeled across it, marking positions of any steelhead parr within 1.2 m of the transect. Parr locations were marked with a weighted flag only when fish appeared to be undisturbed (Beecher et al. 1993). We counted parr, as indicated by flags, in the immediate vicinity (within 1.2 m) of predetermined points on a grid (4.6 × 0.9 m) in the stream, then measured depths and velocities at those points.

After marking positions of any steelhead parr along a transect, we measured depth and mean column velocity (hereafter, velocity, as measured at 0.6 depth) at 0.9-m intervals along the transect. We measured the distance from each marker (parr position) to the transect and recorded the nearest measurement point on the transect.

This sampling procedure yielded a series of cells along each transect. Each measurement point on a transect was the center of a cell 0.9 × 2.5 m. The measurement point was assumed to represent depth and velocity throughout the cell.

We transferred data on location, depth, velocity, and preference factors (P[*d*] and P[*v*]) for each cell and number of parr within each cell to a spreadsheet. We then calculated preference (P[*dv*] = P[*d*] × P[*v*]) for each cell based on measured depth and velocity in each cell at the time of the fish distribution survey.

We used chi-square tests of the null hypothesis that parr distribution is independent of P[*dv*]. Under the null hypothesis, the number of parr in an interval of P[*dv*] would be proportional to the number of cells in the interval. We determined intervals by combining cells until the expected number of steelhead parr was at least 5.0 in an interval, and all cells with the same value of P[*dv*] were in the same interval. For each interval, we tabulated observed number of parr and calculated the expected number of parr (if fish were evenly distributed independently of habitat preferences) within 1.2 m by multiplying total number of parr observed by

TABLE 2.—Distribution of steelhead parr in Morse Creek among cells representing different habitat preferences (P[*dv*]). Distribution data were collected 18 July 1991, at 10°C and a flow of 2.41 m^3/s.

P[*dv*] interval	Steelhead parr in interval: Observed number	Frequency (fish/cell)	Expected number	Number of cells in interval	Chi-square for interval[a]
0.0000–0.0378	0	0.00	5.03	58	5.03
0.0396–0.1512	1	0.02	5.03	58	3.23
0.1700–0.3658	10	0.15	5.81	67	3.01
0.3696–1.0000	10	0.17	5.12	59	4.65

[a] Total chi-square = 15.92, df = 3, $P < 0.005$.

proportion of total number of measurements that were within that interval (Table 2).

Results

The distribution of steelhead parr across P[*dv*] intervals differed significantly from the distributions of cells across P[*dv*] intervals (Table 2). At a streamflow more than triple the flow used for preference curve development, 21 steelhead parr were distributed more frequently than expected in cells with high preference (P[*dv*]), and less frequently than expected in cells with low P[*dv*] (chi-square = 15.93, df = 3, $P < 0.005$; Table 2). None were observed in cells where P[*dv*] = 0. Frequency of fish use of cells increased at each P[*dv*] interval (Table 2).

Discussion

In this study, we tested the hypothesis that depth and velocity preferences determined at one flow (0.86 m^3/s) predict steelhead parr distribution at a different flow (about 3× flow for determining depth and velocity preferences). Chi-square test results are consistent with this hypothesis. Steelhead parr distribution partially verifies the preferences determined at a different flow, thereby validating the assumption of flow-independent preferences.

Shirvell's (1990) observation of a shift of steelhead parr velocity use in response to streamflow change calls an assumption of IFIM into question, but he did not rigorously test the assumption that habitat preference is independent of flow (within a season). The present study, designed to test this assumption, supports it, although the sample size is small.

The apparent consistency in habitat preference between flows is not an artifact of consistent habitat availability between flows. The distribution of depths with velocities changed between flows (chi-square = 117.7, df = 43, $P < 0.001$); the greatest contributions to chi-square came from slow, shallow water (depths <0.15 m and velocities <3 cm/s) and from moderately deep, fast water (depths 0.49–0.76 m and velocities 34–106 cm/s). Slow, shallow water was much more available at the lower flow, and moderately deep, fast water was much more available at the higher flow.

This study, together with our previous report (Beecher et al. 1993) and studies by Shuler et al. (1994), Shuler and Nehring (1993), Gowan (1984), and Hardy et al. (1982), support the IFIM assumption that fish distribution is related to habitat quality as measured in PHABSIM (Bovee and Cochnauer 1977; Stalnaker 1980; Bovee 1982, 1986; Milhous et al. 1984). Shirvell's (1989) correlation between transect suitability and salmon abundance near transects also provides limited support for this assumption. On the other hand, his results indicate that PHABSIM's calculation of spawning habitat suitability for salmon does not adequately predict their distribution. Although none of these studies found perfect matches between fish use and indices of habitat quality, the number of positive associations suggests the assumption is reasonable.

Among the assumptions in PHABSIM are that fish selectively occupy preferred habitat and that preferences for depth and velocity are independent of flow (implied but not stated by Bovee 1982). If the distributions of depths, velocities, substrates, and cover are known and if the relative preferences of fish for different values of these habitat components are known and constant over a range of flows, then fish distribution within a stream should be predictable. In an earlier study (Beecher et al. 1993), we determined habitat preferences of steelhead parr in a stream segment. Then, using independent data sets from an adjacent stream segment at a similar and at a higher streamflow in different years, we found more steelhead parr in areas with high preferences (P[*dv*]) (Beecher et al. 1993; Table 2). Shuler and Nehring (1993) and Shuler et al. (1994) found similar results for brown trout in a Colorado stream.

Standard application of PHABSIM uses three preferences, including substrate or cover in addition to depth and velocity. We disregarded substrate and cover in this study, but we believe this did not compromise our results.

Four factors can lead to imprecision in our predictions of fish distribution: (1) sampling artifacts in preference curve development, (2) single point representation of a cell, (3) the uncertain relation between cell size and fish territory or home range size, and (4) interaction between depth and velocity. Despite these factors and our small sample size, the fact that we still found a relation suggests that it is relatively robust.

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References

Beecher, H. A., T. H. Johnson, and J. P. Carleton. 1993. Predicting microdistributions of steelhead (*Oncorhynchus mykiss*) parr from depth and velocity preference criteria: test of an assumption of the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Sciences 50:2380–2387.

Bovee, K. D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. U.S. Fish and Wildlife Service FWS/OBS-82-26. (Instream Flow Information Paper 12.)

Bovee, K. D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. U.S. Fish and Wildlife Service Biological Report 86(7). (Instream Flow Information Paper 21.)

Bovee, K. D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessments: fisheries. U.S. Fish and Wildlife Service FWS/OBS-77-63. (Instream Flow Information Paper 3.)

Gowan, C. 1984. The impacts of irrigation water withdrawals on brown trout (*Salmo trutta*) and two species of benthic macroinvertebrates in a typical southern Michigan stream. Master's thesis. Michigan State University, Lansing.

Hardy, T. B., C. G. Prewitt, and K. A. Voos. 1982. Application of a physical habitat usability model to the fish community in a spring-fed desert stream. Developments in Environmental Modelling 5:391–397.

Loar, J. M., and ten coauthors. 1985. Application of habitat evaluation models in southern Appalachian trout streams. Oak Ridge National Laboratory Environmental Sciences Division, Publication 2382, ORNL/TM-9323, Oak Ridge, Tennessee.

Mathur, D., W. H. Bason, E. J. Purdy, Jr., and C. A. Silver. 1985. A critique of the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Sciences 42:825–831.

Milhous, R. T., D. L. Wegner, and T. Waddle. 1984. User's guide to the physical habitat simulation system (PHABSIM). U.S. Fish and Wildlife Service FWS/OBS-81/43. (Instream Flow Information Paper 11.)

Reiser, D. W., T. A. Wesche, and C. Estes. 1989. Status of instream flow legislation and practices in North America. Fisheries 14(2):22–29.

Scott, D., and C. S. Shirvell. 1987. A critique of the instream flow incremental methodology and observations on flow determination in New Zealand. Pages 27–44 *in* J. F. Craig and J. B. Kemper, editors. Regulated streams: advances in ecology. Plenum, New York.

Shirvell, C. S. 1989. Ability of PHABSIM to predict chinook salmon spawning habitat. Regulated Rivers: Research and Management 3:277–289.

Shirvell, C. S. 1990. Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) cover habitat under varying streamflows. Canadian Journal of Fisheries and Aquatic Sciences 47:852–861.

Shuler, S. W., and R. B. Nehring. 1993. Using the physical habitat simulation model to evaluate a stream habitat enhancement project. Rivers 4:175–193.

Shuler, S. W., R. B. Nehring, and K. D. Fausch. 1994. Diel habitat selection by brown trout in the Rio Grande River, Colorado, after placement of boulder structures. North American Journal of Fisheries Management 14:99–111.

Stalnaker, C. B. 1980. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. Pages 321–337 *in* J. V. Ward and J. A. Stanford, editors. The ecology of regulated streams. Plenum, New York.

Williams, J. R., H. E. Pearson, and J. D. Wilson. 1985. Streamflow statistics and drainage-basin characteristics for the Puget Sound region, Washington. Volume 1: western and southern Puget Sound. U.S. Geological Survey, Open-File Report 84-144-A, Tacoma, Washington.

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