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Stream-Channel Position of Adult Rainbow Trout Downstream of Navajo Reservoir, New Mexico, Following Changes in Reservoir Release

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Abstract.—Because of potential conflicts between management of reservoir releases for endangered native fishes and tailwater trout fisheries, we used radiotelemetry to monitor channel position of rainbow trout *Oncorhynchus mykiss* during elevated spring reservoir releases designed to benefit native fishes. Fish were monitored at two sites downstream of Navajo Dam, New Mexico: a site with braided channels 0.6 km downstream of the dam and a less complex site 6 km downstream of the dam. Fish were also radio-tagged and monitored during the winter at the upstream site to study movement patterns during low-flow conditions. Of 17 fish monitored during elevated spring discharge, transmitter signals from 5 fish were lost during increased flows; the other 12 fish remained near the point of capture and moved laterally into shoreline and side channel habitats during increased flows. Comparisons between the upstream and downstream sites were confounded by our inability to locate four fish at the downstream site. Fish monitored during winter, low-flow conditions showed little overall movement and no preference for shoreline habitats. Our observations suggest that elevated spring discharge from Navajo Reservoir does not cause long-distance displacement of adult rainbow trout.

Impoundment of large rivers has altered aquatic habitats, benefitting some fish species while harming others (Vanicek 1970; Ward and Stanford 1987). One such alteration occurs in reservoir tailwaters where cold, clear water drawn from the hypolimnion of a reservoir (Baxter 1977; Edwards 1978) can create suitable habitats for salmonids (Vanicek 1970). In the U.S. southwest, most impounded rivers with tailwater trout fisheries also have an imperiled native fish fauna in the warm, turbid lower-river sections (Minckley 1973; Sublette et al. 1990). Typical operation of these dams for irrigation and flood control has been implicated in the decline of many native fishes (Miller et al. 1982; Miller et al. 1989). An alternative management strategy that may benefit endangered riverine fishes (e.g., Colorado pikeminnow *Ptychocheilus lucius* and razorback sucker *Xyrauchen texanus*) would involve the operation of dams to mimic the natural flow regimes that occurred before impoundment (Tyus 1992). This would require increased reservoir releases in the spring followed by gradually decreasing flows into the summer followed by low flows in late summer, fall, and winter. One management concern, however, would be the effect of these flows on the, often economically valuable, tailwater trout fisheries.

Changes in water releases from dams can influence the distribution of stream salmonids by altering the availability and location of optimal habitats within a stream (Cushman 1985; Shirvell 1994; Bowen 1996). Adult salmonids have been reported to decrease movement during increased discharge because of higher energetic costs associated with moving among habitat patches (Heggenes 1988; Bowen 1996). Alternatively, increased flow during spring may induce fish to move from a stream reach. For example, Seegrist and Gard (1972) noted decreased abundance of adult rainbow trout *Oncorhynchus mykiss* after an extreme spring flood in a California stream. Young (1994) also reported long-range downstream movements by several adult brown trout *Salmo trutta* during high spring flows in Wyoming. Young suggested that movement strategies within a population may vary among individuals, some being more prone to move long distances than others. Thus, if high spring releases from reservoirs cause adult trout to move out of reservoir tailwaters, a conflict may arise between the conservation of endangered native fishes downstream and management of tailwater trout fisheries. To address this issue, we monitored movement patterns of adult rainbow trout in response to water releases that simulated historical flow regimes downstream of Navajo.
Figure 1.—Study reach and release sites for adult rainbow trout implanted with radio transmitters downstream of Navajo Dam on the San Juan River, New Mexico.

Dam, an impoundment on the San Juan River in northwestern New Mexico.

Study Site

Our study reach was the 6.4 km of the San Juan River immediately downstream of Navajo Reservoir, New Mexico (Figure 1). This area is managed by the New Mexico Department of Game and Fish as a trophy trout fishery with a daily creel limit of one trout ≥50.8 cm total length (TL). In the upper 61% of this reach, the channel is 50–150 m wide and braided. The channel width narrows to 30–50 m and is predominantly unbraided in the lower reach. Based on measurements taken from six, equally spaced, transects within this reach during low flow (discharge 14 m³/s), current velocities were fairly uniform across the channel at both sites, mean current velocity in the middle of the channel being slightly higher (0.73 ± 0.38 m/s) than near the shores (0.63 ± 0.39 m/s). Mean depth in the upper site was slightly greater (56.3 ± 43.3 cm) than in the lower site (31.6 ± 16.4 cm). Before the construction of Navajo Dam in 1962 there was large annual variation in discharge; peak spring flows frequently exceeded 100 m³/s and some were greater than 200 m³/s. In comparison, postimpoundment discharge has never exceeded 200 m³/s, and 100 m³/s was exceeded in only 6 of the 29 years preceding this study. During our study (1992–1994) peak spring flows were approximately 130 m³/s each year. Since construction of Navajo Dam, water temperatures of the river typically ranged 5–9°C, and turbidity was much reduced, thus favoring high densities of periphytic algae, benthic invertebrates (primarily chironomids), and an introduced population of rainbow trout.

During our study, reservoir releases were regulated by the U. S. Bureau of Reclamation to simulate historical hydrographs: peak discharge occurred during late spring, followed by a gradual decline into midsummer, and low flow thereafter (Figure 2). Although these flows did not duplicate some peak historical flows (>200 m³/s), they are the maximum allowed under current dam safety standards and were greater in magnitude than average peak flows since construction of Navajo Dam.

Methods

Intraperitoneal radio transmitters (Advanced Telemetry Systems, Isanti, Minnesota), encapsulated in epoxy were implanted in 29 adult rainbow trout (range 425–598 mm TL; 800–2,580 g) to monitor movement patterns. Similar transmitters have been previously used to track movements of rainbow...
Figure 2.—Movement patterns of 10 adult rainbow trout (465–598 mm total length [TL]) implanted with radio transmitters in the tailwaters of Navajo Dam. Fish were released 0.6 km downstream of Navajo Dam on 25 March 1992. Upper panel shows discharge during study period for reference.
trout with little effect on their behavior (Mellas and Haynes 1985; Swanberg and Geist 1997). All fish were collected using a Smith–Root 5.0 GPP electrofisher with pulsed DC. At the collection site, fish were anaesthetized in tricaine (200 mg/L), weighted, and measured; transmitters were inserted through a lateral incision in the abdomen such that transmitters would rest above the pelvic girdle (Hart and Summerfelt 1975). Incisions were closed with four or five monofilament polypropylene sutures secured with surgeon’s knots. Sex of most fish was not determined to reduce handling time. After surgery, fish were placed in a holding pen for about 1 h and released within 50 m of the capture site. Transmitter weight ranged from 12 to 24 g and was less than 2% of the body weight (as suggested by Winter 1983) in all but one instance where it was 2.2%. Transmitters had frequencies between 49.200 and 49.840 mHz, and their expected life ranged from 120 to 180 d.

Ten rainbow trout were implanted with transmitters and released on 25 March 1992, approximately 0.6 km downstream of Navajo Dam, which enabled us to follow their movements throughout the period of elevated spring discharge. In addition, 10 rainbow trout were radio-tagged and released in the same location on 3 December 1993 to monitor movements during a winter low-flow period. On 18 March 1994, nine fish were radio-tagged in a lower reach, 5.8 km downstream of the dam, that had a confined channel (Figure 1). Here, we tested the effects of elevated spring discharge on rainbow trout where lateral movement into side channels was restricted because few side channels were available in this reach.

Radio transmitters were monitored weekly from the ground by wading the river with a portable radio receiver and loop antenna. Location of individual fish was determined by triangulation of bearings taken from a minimum of three locations around the fish (Winter 1983). Prior experiments with hidden transmitters indicated this method could accurately locate a transmitter to a 3–5 m² area. If we were unable to locate a fish by wading the river, an approximate location (within 200 m) was determined from canyon bluffs surrounding our study area. Once an approximate location was known, a more exact location was determined by wading as above. In addition, on 12 March 1994 a survey of the lower river by airplane was used to search for fish that we were unable to locate in or study reach. Tracking continued for each individual until the battery of that particular transmitter was predicted to expire. Lateral or upstream movements of all fish located near the end of this period confirmed that transmitters were retained and each fish was alive.

Habitat measurements were recorded each time a fish was located: distance downstream of Navajo Dam (km), channel type (main or side channel), position in channel (middle or shoreline), and depth category (<1, 1–2, >2 m). Distance downstream of the dam was determined along the north bank of the river and marked every 100 m with flagging before the experiments. These flags were used as a reference when a fish was located. Because most habitats occupied by fish were accessible by wading, depth was approximated with a wading staff in the approximate area of the located fish. To estimate the position of the fish in the channel, the river was longitudinally divided into thirds. Thus, one-third of the channel width was considered mid-channel habitat and two-thirds of the channel shoreline habitat.

Wilcoxon’s sign-ranks tests were used to test for differences in the proportion of fish in the various habitats during periods of high and low discharge. These comparisons were made between low flow (<28 m³/s) and high flow (≥28 m³/s) periods. Although this distinction was arbitrary, at flows exceeding 28 m³/s many off-channel habitats (e.g., side channels) appeared to become available to fish.

Results

The number of tagged rainbow trout we were able to monitor long enough to assess the effects of flow varied by sample period. Seven fish were monitored throughout the duration of elevated discharge during spring and summer 1992 (Figure 2). Within the first few weeks, one fish consistently moved downstream and was recaptured in a backwater with a dip net. This fish was emaciated and appeared to have been adversely affected by the surgery. Another fish was caught and kept by an angler on 25 May 1992 in the approximate area of release. Because we had habitat data for this fish at low and high flows, it was included in our statistical analysis. The signal from a third fish was lost as flows increased. Of the eight fish monitored during both high and low flow periods, there was no evidence of long-range movements during increased discharge, and most fish remained within 0.25 km of the release site.

Although there was no major longitudinal movements of rainbow trout during elevated flows, they did move laterally within the channel (Table 1). During elevated flows, there was a significant in-
increase in the percentage of fish using side channels ($Z = -2.197$, $P = 0.028$), and fish also occupied significantly deeper habitats ($Z = -2.366$, $P = 0.018$).

Of the 10 fish radio-tagged in December 1993, nine were followed through February 1994 (Figure 3). One fish was located 6 d after release but not again until 12 March 1994 during an aerial tracking flight 19.7 km from its release site (not shown on Figure 3). Although the transmitter was not recovered, ground-tracking indicated this fish was a mortality or the transmitter was expelled. Otherwise, the only notable change in longitudinal movement of these fish occurred in March 1994 when three fish moved more than 1 km downstream. Few fish occupied side channels, probably because side channels were relative inaccessable during base flows (Table 1). Approximately two-thirds of the contacts were from fish positioned in shoreline habitats, the same proportion predicted by a random distribution (two-thirds of available habitats were shoreline).

We had less success following fish radio-tagged in March 1994 in the lower reach, which was more confined. Two fish were lost in April before any increase in river discharge. An additional two were lost during elevated flows; however, these fish still yielded habitat-use data during low and high flows, and thus were considered in statistical analyses. Two fish were tracked consistently throughout the period of increased discharge, and three others were located intermittently. Of these five fish, there was no apparent downstream movement but two fish moved upstream during the elevated flows (Figure 4). Of the fish with habitat-use data for low and high flows ($N = 7$), fish moved into a side channels on only two occasions (Table 1). There was a significant shift towards shoreline habitats at flows exceeding 28 m$^3$/s ($Z = -2.201$, $P = 0.028$), whereas depth distribution of fish remained constant throughout changes in discharge (Table 1).

### Discussion

Adult rainbow trout implanted with radio transmitters exhibited several movement patterns but generally did not move downstream during increased spring releases from Navajo Dam. Although it is possible the fish carrying transmitters with lost signals moved out of our study reach, the majority (12 out of 17) remained near the point of capture and tended to move laterally into side channels (upper site only) and shoreline habitats during increased flows.

During increased flows fish that remain within our study reach presumably sought optimal habitats [i.e., low velocity with high shear (Shirvell 1994; Bowen 1996)] near the shore or in side channels. However, other factors, such as suitable spawning habitat and prey abundance, may also explain these lateral movements within the channel. Between-site comparisons of habitats used by rainbow trout were hampered by our inability to locate several fish during increased spring discharge. However, in the lower site, where side channels are rare, the fish used shoreline habitats during high flows instead of traveling up or downstream in search of side channels.

Physical habitats that provide shelter from increased current velocity are important in determining the resistance of stream fish assemblages to periods of increased discharge (Glova and Duncan 1985; Heggenes 1988; Pearsons et al. 1992). Pearsons et al. (1992), showed that fish assemblages in stream reaches with more complex habitats had greater resistance to and resilience from flood events than in less complex reaches. At a smaller scale, Heggenes (1988) showed that brown trout used low-velocity habitats provided by coarse substrate during artificial increases in flow. On the San Juan River, both shoreline and side channels appear to provide suitable habitats during increased discharge.

In the spring of 1994, monitoring from the

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**Table 1.** Comparisons of habitat use by rainbow trout between low-flow (<28 m$^3$/s) and high-flow (≥28 m$^3$/s) periods on the San Juan River downstream of Navajo Dam, New Mexico. Significant differences ($P < 0.05$) between high- and low-flow periods were determined by a Wilcoxon’s sign rank test and are noted by asterisks.

<table>
<thead>
<tr>
<th>Sample period</th>
<th>df</th>
<th>Percent of fish occupying main channel</th>
<th>Percent of fish occupying mid-channel</th>
<th>Mean depth category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;28 m$^3$/s</td>
<td>≥28 m$^3$/s</td>
<td>&lt;28 m$^3$/s</td>
</tr>
<tr>
<td>Spring 1992</td>
<td>8</td>
<td>79.3 (±30.6)*</td>
<td>50.0 (±29.9)</td>
<td>62.6 (±10.1)</td>
</tr>
<tr>
<td>Winter 1993–94</td>
<td>9</td>
<td>84.8 (±14.9)</td>
<td>75.0 (±10.0)</td>
<td>62.6 (±10.1)</td>
</tr>
<tr>
<td>Spring 1994</td>
<td>7</td>
<td>100 (±0)</td>
<td>95.9 (±10.0)</td>
<td>38.7 (±19.1)*</td>
</tr>
</tbody>
</table>
Figure 3.—Movement patterns of nine rainbow trout (446–526 mm total length [TL]) implanted with radio transmitters in the tailwaters of Navajo Dam. Fish were released 0.6 km downstream of Navajo Dam on 3 December 1993.
Figure 4.—Movement patterns of nine rainbow trout (425–574 mm total length [TL]) implanted with radio transmitters in the tailwaters of Navajo Dam. Fish were released 6.3 km downstream of Navajo Dam on 18 March 1994.

ground and fixed-winged aircraft within a 16-km reach below Navajo Dam failed to locate four fish at the lower site. It is unknown if these fish moved downstream or were lost because of (1) injury from surgery or electrofishing, (2) capture and removal by anglers, or (3) faulty transmitters. Because of the low conductivity (<400 μmho/cm) and shallow depth (<5 m) of the San Juan River, radio-
transmitter signals should have been relatively strong, even in the deepest pools (Winter 1983). Thus, it is unlikely we missed these fish in our extensive search of the river. It is possible a small fraction of fish moved large distances downstream during increased discharge. If so, this would conform to the results of Young (1994) and Gowan et al. (1994) that individuals within a population can exhibit different movement strategies.

Fish that were monitored during winter base flows generally showed little movement. Three fish, however, made substantial downstream movements near the end of February, further supporting the hypotheses that individuals within a population have different movement strategies (Gowan et al. 1994; Young 1994). Other studies have indicated both limited movement of trout during winter (Bowen 1996) and increased movement during the spring (Meyers et al. 1992). Observed movements of rainbow trout during late spring were probably associated with spawning activity rather than a response to increased flow (Sublette et al. 1990; Pfieger 1997).

Most studies on trout movement have examined fish response to rapid fluctuation in discharge below dams (e.g., Heggenes 1988; Pert and Erman 1994) or reduction of flow by diversion of stream water (Kraft 1972). Our study considered the effect of elevated flows for extended periods that may enhance native fish habitat in the lower reaches of the San Juan River. Because of our small sample size and inability to locate several fish, we cannot dismiss the possibility that a small proportion of these fish moved in response to flow increases. However, most fish made lateral movements towards shore or side channels, suggesting these flows only caused a shift in position of preferred habitats and overall did not affect habitat availability or quality in our study reach. In a related study on the San Juan River (L. Ahlm, unpublished data), adult rainbow trout had higher mean condition (weight/total length) in September 1992 (1.24 ± 0.12; N = 998), after 3 months of high flows, than during low flows in February 1992 (1.14 ± 0.19; N = 724), further suggesting these flows did not adversely affect health of adult rainbow trout.

Our study was limited to the effects of elevated flows on adult rainbow trout, and younger trout may be affected differently. For example, Bowen (1996) showed that younger trout (<33 cm TL) moved more during unstable discharge than did adults. However, in the San Juan River the majority of individuals are large adults (72.7% of individuals are >33 cm TL [L. Ahlm, unpublished data]). Thus, evidence from this study suggests that potential flow needs of native fishes are not in conflict with management of flows for rainbow trout.

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