ENTRAINMENT OF FISHES FROM THE SOUTH PLATTE RIVER INTO FULTON DITCH, 1998

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Executive Summary

Sampling was conducted in Fulton Ditch to determine the species composition and entrainment rates of early life stages of fish from the South Platte River during the irrigation season. The goals of this study were to: 1) confirm whether fish (eggs, larvae, juveniles, adults) are entrained into the Fulton Ditch and, 2) assess the proportion of fish (eggs, larvae, juveniles, adults) being entrained into the Fulton ditch versus those not entrained. Goal one was accomplished by qualitative sampling to determine presence or absence of fish in the ditch and the river. Goal two was accomplished by measuring entrainment rates of marked fish larvae and buoyant beads into Fulton Ditch from the South Platte River.

A total of 17 fish species was detected in Fulton Ditch and associated aquatic habitats including Bull Seep. Species richness and fish abundance of the Fulton Ditch fish community was relatively high near the diversion but declined quickly downstream. The most common species collected were native fathead minnow *Pimephales promelas,* and white sucker *Catostomus commersoni*, both of which were abundant in the South Platte River. The only rare native species captured in the ditch, Iowa darter *Etheostoma exile*, likely originated from habitat in tributary Bull Seep. Other rare native species are unlikely to be affected by entrainment because they do not occur in the degraded South Platte River habitat. The most abundant non-native species, largemouth bass *Micropterus salmoides*, would be unlikely to establish a viable river fishery because of lack of suitable adult habitat. Thus, it is unlikely that fish entrainment into Fulton Ditch reduced species richness of the South Platte River fish community.

We documented that fish larvae and buoyant beads released into the South Platte River were entrained into Fulton Ditch. A total of 382,556 marked white sucker larvae were released and a 12,369 were re-captured in Fulton Ditch on five different release occasions. Entrainment rates from the South Platte River into Fulton Ditch were proportional to the amount of water diverted into the ditch. At low rates of diversion during a 30 April 1998 release, we estimated that 1.5% of all fish released were entrained into Fulton Ditch even though we expected that 4.3% of all fish would be entrained. Bead entrainment rates were also lower than expected at low diversion rates. Thus, at low rates of ditch diversion, entrainment rates were lower than we

expected. At higher ditch diversion rates during four releases on 12 and 14 May, we estimated that an average of 17.0% of all fish released were entrained into Fulton Ditch even though we expected only 6.2% to be entrained. Higher than expected entrainment rates were likely due to release of fish exclusively on the bank where the headgate occurred and concentration of sampling in areas of the ditch where larvae were concentrated. After accounting for those potential biases, we hypothesized that entrainment rates during periods of high ditch diversion rates were probably proportional to water diversion rates. The importance of entrainment loss to Fulton Ditch may be species-specific and depend on the timing of appearance of larvae relative to overall river discharge and rates of diversion. The most severe impacts may occur in summer when river discharge is low and ditch diversion rates are relatively high.

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INTRODUCTION

Irrigation diversions and canals are ubiquitous features of flowing water ecosystems in the arid American West because of irrigated agriculture. Irrigation diversions and canals indirectly affect biota in streams by blocking upstream dispersal routes and altering downstream flow regimes. Aquatic invertebrates, early life stages of fish species that reproduce during spring and summer, and adult fish may also be entrained directly into irrigation canals and lost to the river ecosystem. Rates of fish entrainment and loss to irrigation canals has been extensively studied for commercially valuable salmonids in the Pacific Northwest (see unpublished references in Buell 1996, others). However, little is known about entrainment rates of non-salmonid biota into irrigation canals, including those found in Colorado streams.

The South Platte River, Colorado, which headwaters upstream of the Denver metropolitan area, serves as a major source of agricultural irrigation water as well as municipal water. Metro Wastewater Reclamation District (Metro), which provides wastewater treatment for over 1.3 million people and 55 municipalities in the greater Denver area, discharges an average of 570 million liters of effluent daily to the South Platte River. Because upstream canals divert most water for reservoir storage or irrigation, Metro-treated effluent often contributes 90% or more of the water in the South Platte River for a considerable distance downstream. A unique situation results because the treated effluent creates a river, but by existing water quality standards, that same river must have ecological integrity similar to a non-effluent dominated system.

In an effort to improve the ecological integrity of the South Platte River, Metro entered into a Memorandum of Understanding (MOU) with various agencies including the U.S. Environmental Protection Agency, Colorado Water Quality Control Division, and Colorado Division of Wildlife. In the MOU, Metro agreed to institute measures to improve the general health of the South Platte River downstream of the Denver metropolitan area. One means to improve river health was to increase fish production and species richness. One possible method to accomplish this was to screen Fulton Ditch, an irrigation canal downstream of Metro, to reduce fish entrainment and loss from the South Platte River. Prior to testing of fish screens, it was imperative to understand the species composition and entrainment rates of early life stages of fish from the river into Fulton Ditch. Therefore, the goals of this study were to:

1) To confirm whether fish (eggs, larvae, juveniles, adults) are entrained into the Fulton Ditch and,
2) Assess the proportion of fish (eggs, larvae, juveniles, adults) being entrained into the Fulton ditch versus those not entrained.

Goal one was accomplished by qualitative sampling to determine presence or absence of fish in the ditch and the river. Goal two was accomplished by measuring rates of transport of fish larvae in the South Platte River and the Fulton Ditch to determine percentage of fish entrained. This report presents results of that research.

STUDY AREA

Fulton Ditch in Adams County, Colorado, is located approximately 8 km downstream of Metro in the northeast Denver metropolitan area. The diversion dam and Fulton Ditch (ditch) provides South Platte River water for vegetables, feed grain, hay, and pasture from about mid-March through October. Discharge level in Fulton Ditch during the 1998 irrigation season (March through October) was dependent upon irrigation needs but generally ranged from 0.42 to 2.83 m^3/sec (pers. comm., G. McDonald, Henderson, CO). During the remainder of the year when the headgate is closed, Fulton Ditch is dry with the exception of local groundwater seeps and a small amount of flow from Bull Seep, a cool spring-fed tributary (Fig. 1). On 3 September, the ditch was flowing at 1.42 m^3/sec, was 0.5 to 1.8 m deep, and water was 23 °C. Substrate was mostly sand or silt, although small amounts of gravel occurred in some areas. Abundant rooted macrophytes were present throughout the ditch and provided cover for fishes. The pool in Bull Seep below the 100th Avenue crossing was > 1.5 m deep, had silt substrate, and the water temperature was 19.5 °C during September sampling.

South Platte River discharge in 1998 was variable and high during most of the spring (Fig. 2). Mean daily discharge during May was 48.8 m^3/sec. Mean daily discharge was 51.5, 59.2, and 53.5 m^3/sec on 30 April, 12 May, and 14 May, respectively, the days when releases of marked larvae were made into the river. All discharge data used are preliminary (pers. comm., Dave Dzurovchin, Office of the State Engineer, Division of Water Resources).

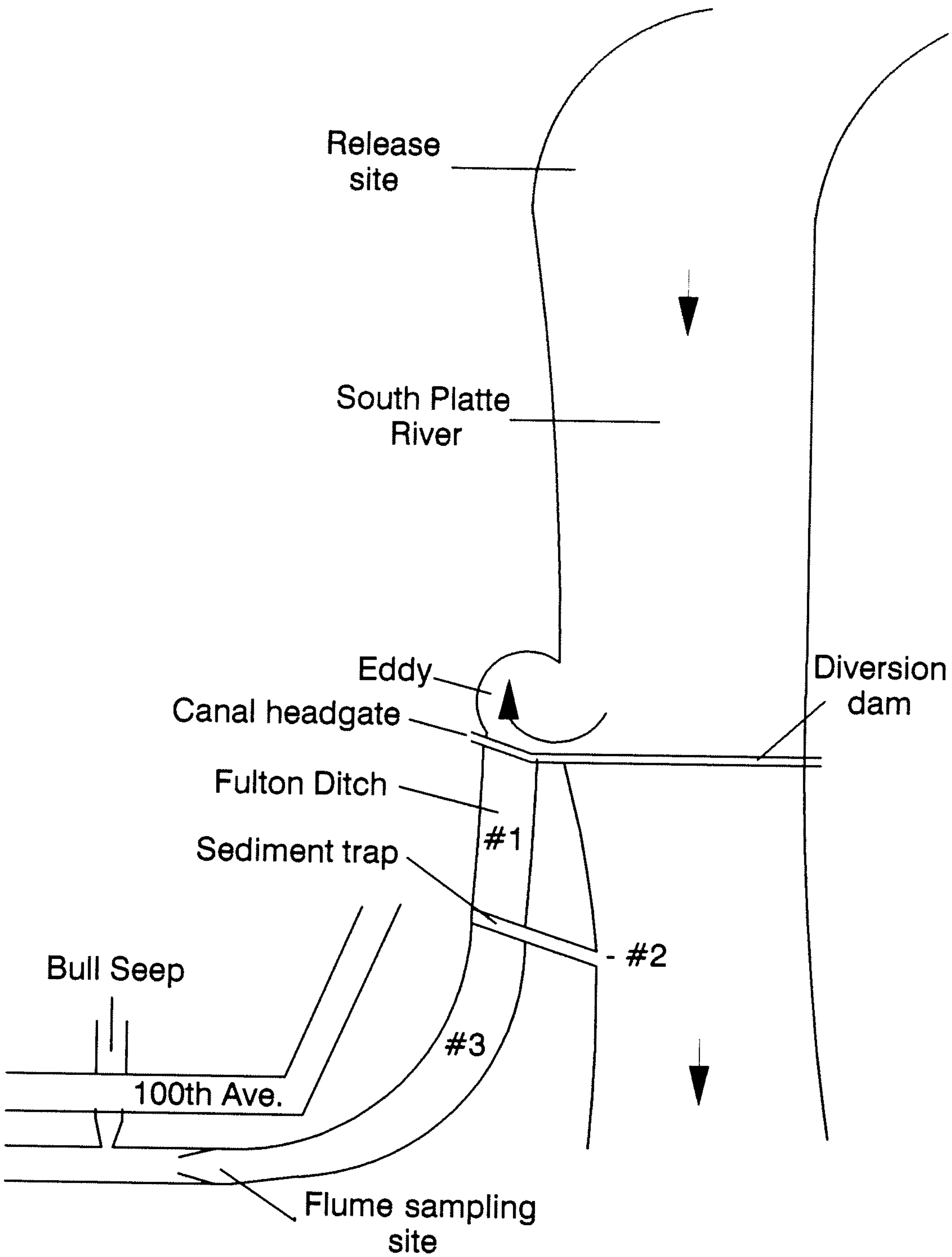

Figure 1.--Map of study area. Arrow indicates direction of flow of the South Platte River. The map is not drawn to scale in order to show needed detail. The distance from the release site to the diversion dam is about 0.5 km and the distance from the headgate to the flume sampling station is about 100 m. Numbered locations 1, 2,3 indicate water diverted, water returned via the sediment trap to the river, and water passed down the canal, respectively, and aid understanding of how calculations were made in Methods.

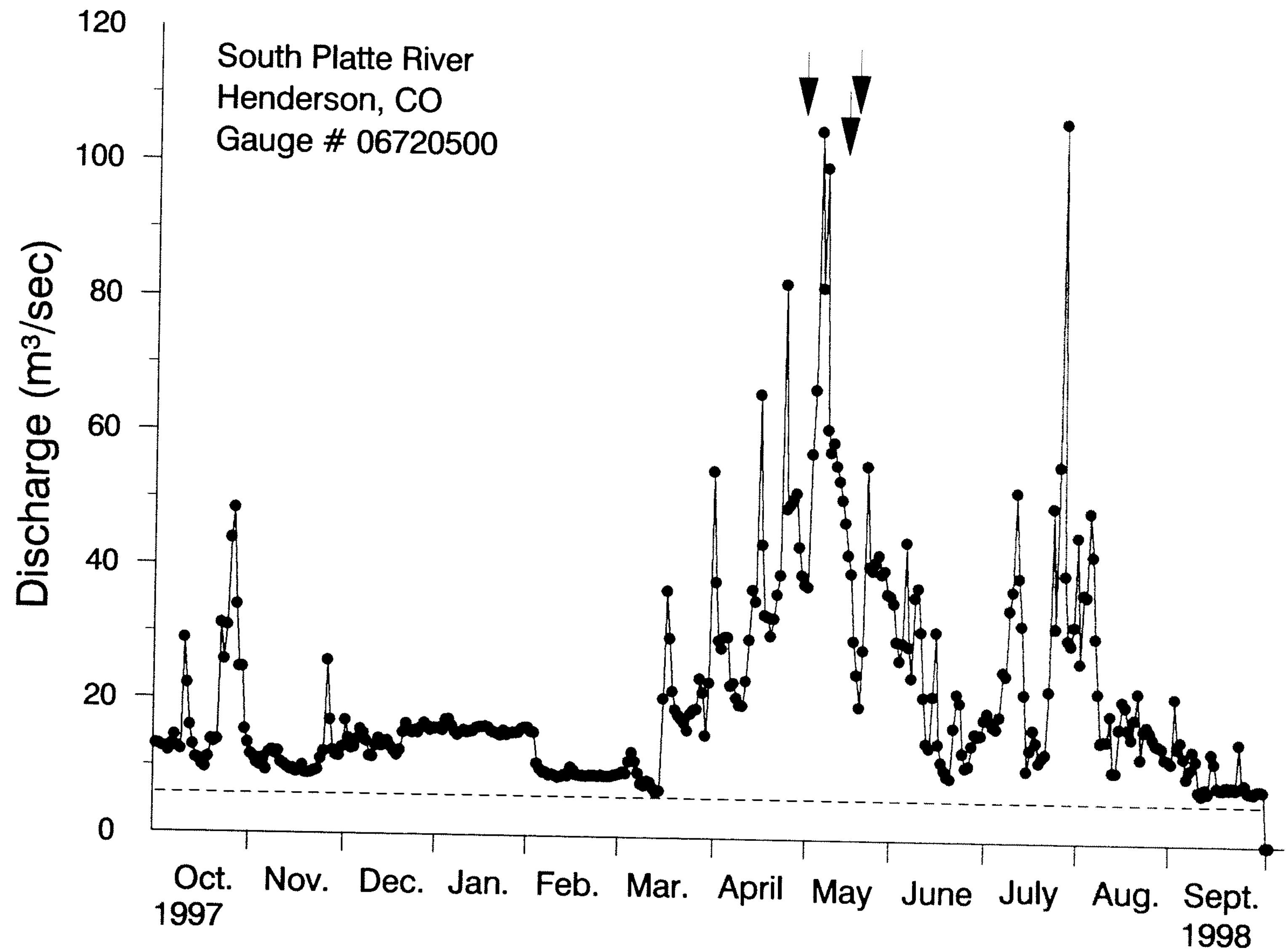

Figure 2.--Mean daily discharge (m^3/sec) for the South Platte River at Henderson, CO, 1998 (U. S. Geological Survey gauge # 06720500). Arrows indicate fish or bead releases into the South Platte River. The dashed line represents the approximate contribution of Metro effluent to the South Platte River in the relatively high water year 1998.

METHODS

Fulton Ditch Fish Community Composition

Fish community composition in Fulton Ditch and Bull Seep was assessed on 3 September (N = 5 samples) and 6 November (N = 5) by seining (seine dimensions 4.6 m long, 1.8 m deep, 4.8 mm mesh). On each occasion, fishes were sampled in Bull Seep, in Fulton Ditch just upstream and downstream of the seep, and at 104th Avenue. On 3 September, a fifth sample was collected in a small downstream lateral. On 6 November, a fifth sample was collected in Fulton Ditch between the sediment trap and the flume. Discharge in Fulton Ditch was relatively high during September seining (1.42 m^3/s). The swift and deep current and luxuriant bank and in-canal vegetation required that eight seine hauls be made at each location to adequately sample all habitat types. During November sampling, flow was negligible because the headgate was closed so habitat was limited to simple pools which could be sampled with two to four seine hauls per site. Most specimens were identified and released although some vouchers were preserved on each sampling occasion. Common and scientific names of fishes used in this report are in Appendix I.

Entrainment rate estimation

This portion of the study was designed to measure rates of entrainment of fish into Fulton Ditch. Because of their relatively poor swimming ability, early life stages were thought the ones most likely to be entrained into Fulton Ditch and received the primary focus of this portion of the study. Release of marked larvae into the South Platte River was considered the most efficient means to assess entrainment rates of fish into Fulton Ditch because sampling effort could be concentrated during times when known quantities of fish were present in the river. This was important because drift samples from enriched and algae-laden rivers such as the South Platte are extremely time consuming to process. An alternative was sampling naturally produced larvae. However, such a sampling scheme would give uncertain estimates of entrainment rates because timing of reproduction and abundance of drifting larvae was unknown. Use of marked larvae allowed differentiation of naturally produced and cultured fish, should reproduction of wild fish overlap with releases. Beads were also used as a fish surrogate to estimate entrainment rates. Beads were obtained from a commercial supplier (TFF, Inc., Amityville, NJ) and were composed of a gum-based, bio-degradable, and non-toxic substance. The bright yellow beads were 4 to 6 mm in diameter and were just buoyant in water 10 to 25°C.

Fish culture.--Most effort was concentrated on obtaining larvae of white sucker *Catostomus commersoni*. Adult white suckers have large body size, high fecundity, and they spawn in spring. Therefore, larvae would be available for release experiments prior to snowmelt and high spring discharge. White sucker is also native in the South Platte River Basin, Colorado and is common in that segment of the river. Efforts to obtain larvae of fathead minnow *Pimephales promelas*, a summer-spawning native cyprinid with relatively small larvae, were unsuccessful.

Procedures for catostomid fish culture were adopted from Hamman (1981). Adult white suckers were captured from Horsetooth Reservoir near Fort Collins, CO, and held in concrete raceways at the Foothills Campus Aquatic Laboratory. Water temperatures in Horsetooth Reservoir and the well at Foothills Campus were 7°C. Only a few male white suckers were tuberculate and ripe. To enhance maturation of gonads, warm water was pumped from an outdoor pond and mixed with raceway water to achieve a daytime high temperature of 13°C. Four days after raceway water was warmed the fish were ripe. The ventral surface of each female was wiped dry, and eggs of 2-4 females were stripped into a dry plastic pan. Sperm from one to two males was added along with about 350 ml of water and the mixture was carefully stirred for about 2 min. Fertilized eggs (embryos) were quickly rinsed with water and 0.5 liters (L) of bentonite slurry the consistency of thin pancake batter was added. Embryos were stirred for up to 5 min or until embryo adhesion was not evident and then carefully rinsed until most bentonite was removed. Fertilized embryos were placed in Ziplock bags and transported to the Aquatic Research Laboratory (ARL) for rearing.

Bags of embryos were tempered over a 1 to 3-hr period to the 16°C ARL well temperature; temperature increases of up to 8°C had no noticeable affect on embryo viability. Total embryo volume was measured and five 5 ml subsamples were enumerated to estimate total egg numbers. Fertilization rates were also estimated from subsamples. Embryos were incubated in either flow-through circulating jars, Heath trays, or in mesh baskets suspended in aerated troughs. Most larvae hatched after 6 d and were transferred to aerated and flow-through troughs that were screened with Nitex (500 μm mesh size).

Fish marking.--Larvae were marked two to four d posthatch in 1.3 m-long troughs in a solution of buffered (tris buffer, pH about 7.5) tetracycline hydrochloride (TC). Trough volume was reduced to about 23 L of well water and an additional 23 L of TC solution made with deionized water was added to achieve a solution concentration of 350 mg/L TC. Troughs were aerated, covered, and larvae immersed for six hours. In the initial marking batch, heavy surface foam was produced by fine-pore aerators. Subsequent batches were marked in troughs aerated by larger-bore pipettes. Dissolved oxygen levels were monitored throughout and were generally maintained at or above 4 mg/L. After 6 hr, troughs were flushed clear and flow-through conditions resumed.

Field sampling to assess sediment trap efficiency.--Fulton Ditch is equipped with a sediment trap designed to flush sand entrained under the headgate and into the canal back to the river. The sediment trap is a trough cut into the concrete pad downstream of the headgate, and is angled downstream about 30 degrees. The trough spans the entire concrete pad and is about 40 cm wide x 40 cm deep. As water flows down the canal, sand drops into the trough and is swept back to the river through a short canal by the rapidly flowing vortex of turbulent water. We sampled the efficiency of the sediment trap to return fish back to the river because deviations from 100% efficiency would change the number of fish expected at the downstream Parshall Flume sampling station. This is especially important at relatively low ditch flows because a relatively large and constant volume of water is required for proper sediment trap operation.

To assess trap efficiency, a batch of beads and 9 or 10 d-old larvae (N = 1,000 each) were released just below the headgate and upstream of the sediment trap. Trap efficiency was tested on 30 April when 2.63 m^3/s of water was diverted under the headgate and again on 13 May when 4.07 m^3/s was diverted under the headgate; water returned through the sediment trap on each occasion was nearly identical at 1.24 m^3/s and 1.32 m^3/s, respectively. Total sediment trap discharge was estimated by measuring the width, height, and velocity of the sediment trap water plume. Beads and fish were released into the middle of the canal and were carried to the sediment trap trough almost instantaneously. Thus, there was little chance for fish or beads to disperse or remain upstream of the trap. A single drift net was placed in a portion of the plume of sediment trap outflow for 120 or 180 seconds after the release, a period ample for all larvae and beads to either pass through or by the trap. Water velocity sampled by the drift net was estimated by the flow meter placed in the net mouth. The sample was fixed and fish were sorted from debris and enumerated in the lab. Tests were replicated five times on 30 April and four times on 13 May. Beads captured in the net sets were pulverized by the turbulent flows so estimation of bead capture rates was not possible.

The total number of fish captured in the sample was divided by the proportion of total sediment trap discharge sampled by the drift net to yield an estimate of the total number of fish returned to the river. For example, if 100 fish were captured in the sample and 20% (0.20) of the trap discharge was sampled, the estimated number returned would be 100/0.20 or 500 fish. That estimate was compared to the number of larvae expected to be returned under the null hypothesis that the return rate was proportional to the amount of diverted water that is returned to the river through the trap. In other words, if 2.44 m^3/s of water is diverted into Fulton Ditch (denoted as location 1 in Fig. 1) and 50% (1.24 m^3/s, the actual trap flow rate) was returned to the river (denoted as location 2 in Fig. 1), it was our expectation that the trap would be 100% efficient and return 50% of the fish released at the headgate back to the river. Similarly, 50% of the water and fish would be expected to pass down the canal (denoted as location 3 in Fig. 1).

Field sampling and releases to estimate fish entrainment.--The initial sampling and assessment design involved several releases of beads and marked larvae at the upstream end of the diversion pool. Larvae and beads were to be distributed at several locations across the river, a pattern which would reflect distribution of naturally produced larvae. Following fish releases, drift samples would be collected downstream in both Fulton Ditch and the South Platte River below the diversion dam. Assuming relatively high capture rates and relatively low river flows (< 14.2 m^3/s), this sampling scheme would have allowed estimation of timing and entrainment rates of larvae into the canal, and timing and passage rate of larvae downstream. Estimation of downstream passage rates were needed because larvae retained upstream in the low-velocity diversion dam pool would confound estimates of ditch entrainment rates.

Discharge levels of the South Platte River at the time of fish releases were 51.3 to 61.3 m^3/s, or about three to four times higher than anticipated. This necessitated simplification of the sampling design in the following manner. All sampling (N = 9 drift nets) was conducted in Fulton Ditch in order to obtain a more robust estimate of fish entrainment rates. Observations of water velocities throughout the diversion pool suggested that all larvae would be quickly swept downstream into the ditch or downriver. Thus, potential confounding of entrainment rates by fish retention in the pool upstream of the diversion dam was not a concern. Releasing marked larvae across the river was impossible because of high discharge. Instead, all beads and fish were released along the right bank where the Fulton Ditch headgate was located. Release of all fish and beads along the headgate side of the river increased the chances of entrainment into the ditch. Thus, sample data would allow us to estimate entrainment rates under a "worst-case" scenario. It was anticipated that entrainment rates estimated from this approach would then be scaled downward, based on the likely distribution of naturally produced fish larvae and consideration of other factors which may have increased our sampling efficiency and capture rates.

On release days, the number of available larvae was estimated volumetrically in the ARL. This was accomplished by first measuring the entire volume of fish larvae in a graduated cylinder. Then, several (3 to 5) smaller-volume subsamples of fish were enumerated to yield an average number of fish/ml. That quantity divided into total fish volume yielded an estimate of total fish. Consistent estimates of fish in such subsamples (e.g., 118, 116, and 108/ml, mean = 114 fish/ml) gave us confidence that estimated numbers of fish released were accurate. Fish were placed in 3.8 L Ziplock bags (about 5,000/bag), filled with oxygen, sealed, and placed in coolers for transport to the study site. At no time did fish appear stressed. No mortalities were observed in small samples of fish retained overnight after release of the main batch. This gave us confidence that fish were alive and in good condition at time of release.

The nine conical drift nets (0.15 m^2 mouth area, 4 m long, 560 μm mesh) used for sampling were staked into Fulton Ditch at the head of the Parshall Flume with reinforcement bar prior to fish and bead releases. Removable PVC sample buckets were attached to the 10 cm cod-end of the net with hose clamps. Nets were placed side-by-side across the canal on the outside (north) of the ditch meander to maximize capture of larvae during the 30 April release. In subsequent releases on 12 and 14 May, nets were evenly spaced so that all portions of the channel were sampled. In both arrangements, 5 m of the surface of the 8.5 m-wide ditch was sampled. A General Oceanics flow meter (model 2030) suspended in each net mouth recorded water velocity during the net-set; duration of each set was also recorded. The nine nets sampled 20 to 33 % of the total ditch volume; the percent volume sampled decreased as ditch discharge increased.

After nets were set, fish and beads were transported upriver about 0.5 km to the release site at the head of the diversion pool. Beads and larvae were released near the right (east) river bank but in the current to ensure downstream transport. At the flow levels present during most releases, beads and presumably fish, were detected at the diversion headgate in < 10 min after release.

Sampling time for an individual net was generally 2 hr or less because of the large volume of debris and filamentous algae. Nets were carefully rinsed, and contents were strained, labeled, placed in 3.8 L Ziplock bags, and fixed with 100% ethanol in a quantity at least equal to that of the sample. Ethanol fixation and preservation of specimens generally does not deteriorate the otoliths which were needed for TC mark assessment. Nets were replaced as soon as the sampled was collected so that sampling was essentially continuous.

Laboratory procedures.--In the laboratory, samples were carefully sorted and fish were preserved in 100% ethanol. Some beads deteriorated quickly in the samples compromising the usefulness of that data. Fish were identified, enumerated, and subsamples of 20 fish captured after each release (N = 100 total) were selected for otolith analysis. Otoliths were extracted, placed on microscope slides, and covered in immersion oil. Otoliths were examined at 200x magnification with a fluorescent light source to detect the presence of the tetracycline mark. Number of unreadable otoliths was also recorded.

Bead entrainment rates.--A bead-only release experiment was made in the South Platte River on 27 October. Fulton Ditch flows were relatively low (0.42 m^3/s) and discharge in the South Platte River was about 28.3 m^3/s. This experiment was conducted because data gathered during previous releases was compromised because of poor bead preservation. To eliminate the need to preserve beads, we sampled beads by sweep netting them from the ditch. This allowed enumeration immediately after their capture. Prior to river bead releases, we evaluated the efficiency of this capture technique by releasing three separate lots of 500 beads each (estimated volumetrically) in the ditch just downstream of the sediment trap. Beads were transported about 100 m downstream to the flume sampling station where three netters sampled them. The resulting capture rate information allowed us to estimate the probability of capturing a bead if it entered the canal and was swept past the sediment trap. This would allow us to adjust our estimated bead entrainment rates if we were less than 100% efficient at capturing beads in the canal.

After sweep net efficiency tests were completed, a lot of 10,000 beads was released in the river current at the upstream release point. Entrained beads were sampled by sweep netting in the ditch for about 60 minutes after the release, and the beads were placed in a labeled jar in water. A total of three releases were made. Inspection of the eddy just upstream of the headgate suggested that few beads remained upstream of the diversion dam after that amount of time. In the laboratory, beads were enumerated.

Entrainment rate calculations.--Entrainment rate data analysis involved comparison of number of beads or fish observed in samples to the number of beads or fish expected. The observed number of beads or fish entrained was generated from captures in sampling efforts. The total number of fish captured in samples collected during the appropriate post-release interval, usually 4 to 6 hours, was divided by the proportion of flow that the nets sampled during that same period. That yielded an estimate of the total number of fish transported past the sampling station. Bead entrainment rates captured by sweep netting were simply the total number of beads captured because sampling efficiency was high.

Our null hypothesis for expected entrainment rates was that beads or fish in the river would be entrained into the canal in proportion to the amount of river flow diverted. Therefore, calculation of the expected number of beads or fish entrained was simply the proportion of the flow of the whole river that was diverted multiplied by the total number of beads or fish released. For example, assume that 10,000 fish were released into the river which was flowing at 50 m^3/s.

If 10% or 5 m^3/s were diverted, one would assume that 10%, or 1,000 fish would also be entrained and be in the canal upstream of the sediment trap.

Because the sediment trap was returning water to the river during all bead and fish releases, we had to adjust the expected number of beads or fish captured at the ditch sampling site downstream of the sediment trap by the relative amounts of water returned to the river. We also adjusted the expected number of beads or fish captured by considering the relative efficiency that the sediment trap returned fish to the river. Carrying the above example further, assume that 25% (1.25 m^3/s) of the diverted flow (5 m^3/s) is returned to the river. If the trap is 100% efficient the quantity of fish expected in the ditch downstream of the sediment trap is simply:

$$N_{(e)} = X_1 * N_{(c)},$$

and the number of fish returned to the river is:

$$N_{(r)} = X_2 * N_{(c)},$$

where X_1 is the proportion of diverted flow that continues downstream of the sediment trap (here 0.75), X_2 is the proportion of diverted flow that is returned to the river (here 0.25), and $N_{(c)}$ is the number of fish entrained. In this example $N_{(e)}$ is 750 fish (0.75*1000) and $N_{(r)}$ is 250 fish (0.25*1000). If efficiency of the sediment trap to return fish to the river is something other than 100 %, a second term must be added to the calculation of $N_{(e)}$ as follows:

$$N_{(e)} = X_1 * N_{(c)} + X_2 * N_{(c)} * (1-E),$$

where all factors are defined as above and E is the efficiency with which fish are returned to the river via flows out of the sediment trap. Assuming the same example above with the additional condition that E is only 40% or 0.4, the estimated quantity of fish downstream of the sediment trap is estimated as:

$$N_{(e)} = 0.75*1000 + 0.25*1000*(1-0.4) = 900.$$

Thus, in this example fish are returned to the river at a rate lower than the rate at which discharge is returned. Alternatively, if the sediment trap returned fish to the river at a rate higher than the proportion of flow that is returned to the river (e.g, efficiency > 100%), $N_{(e)}$ would be adjusted downward.

RESULTS

Fulton Ditch Fish Community Composition

A total of 1,899 fishes in 17 species were detected in samples collected in Fulton Ditch and Bull Seep (Table 1). Included in these samples were the few fish captured in drift net samples that were not marked and released by us. In general, most fish captured in Fulton Ditch were just up- or downstream of Bull Seep; fish abundance was very low in samples collected 104th Ave. and the lateral canal.

Fathead minnow was the most common and widespread species in the system, and was particularly abundant in the sample collected in the ditch downstream of Bull Seep after diversions ceased in November 1998. Largemouth bass was the second-most abundant species collected and were found at most ditch sites during most times. Several hundred additional bass were noted in the drying pool downstream of the flume upstream of Bull Seep in November. No particular habitat associations were noted for bass, which likely utilized in-channel macrophytes for cover. The length range for largemouth bass in one September sample (Fig. 3) suggested that all individuals were age-0 fish (hatched in summer 1998) and all were in good condition. Bass were uncommon in Bull Seep and downstream at the 104th Avenue site. White sucker was the third most common species and was collected at most sites during both sampling occasions. Fathead minnow, largemouth bass, and white sucker comprised 86.2 % of all fish captured in the system.

Brook stickleback, green sunfish, bluegill, black crappie, and longnose sucker were the next most common species captured but were only locally common. For example, most brook sticklebacks and Iowa darters, and all black bullheads were captured in Bull Seep. Other species of interest were a single adult spottail shiner and three walleye larvae. The walleye larvae captured in drift nets on 30 April were 8.0, 8.0, and 8.5 mm TL, and one still retained yolk, which suggested a very recent hatching date.

Table 1.--Composition of fishes collected at six Fulton Ditch area sites on 3 September and 6 November, 1998. Site 1 in Fulton Ditch upstream of the Parshall Flume and downstream of the sediment trap, Site 2 was just downstream of the flume, Site 3 was in Fulton Ditch just downstream of Bull Seep, Site 4 was in Bull Seep, Site 5 was Fulton Ditch at 104th Ave. crossing, and Site 6 was a downstream lateral. Drift net captures of fish that we did not release are also included.

Species	Site 1	Site 2		Site 3		Site 4		Site 5		Site 5	Drift			
	Nov.	Sept.	Nov.	Sept.	Nov.	Sept.	Nov.	Sept.	Nov.	Lateral	nets	Total	%	Rank
common carp					1							1	0.1	17
golden shiner					2							2	0.1	14
spottail shiner						1						1	0.1	17
sand shiner		1										1	0.1	17
fathead minnow	13	143	171	14	722	1	4	14	11	4	2	1098	57.9	1
longnose sucker	24	2						1	2			29	1.5	8
white sucker	95	2	26	2	14	1	1	17	18			176	9.3	3
black bullhead								2				2	0.1	14
brook stickleback	1	7	1	5	6			14	38			72	3.8	4
western mosquitofish			1	10								11	0.6	11
green sunfish	4	2	13	3	13			2				37	1.9	6
bluegill	4		3	1	18			11				37	1.9	6
largemouth bass	27	66	205	22	12	20		3	5			360	19.0	2
black crappie	2		7	2	4			4	12			31	1.6	7
Iowa darter					2			17				19	1.0	9
yellow perch		11	7									18	0.9	10
walleye											3	3	0.2	12
	170	234	434	59	794	23	5	85	86	4	5	1899		

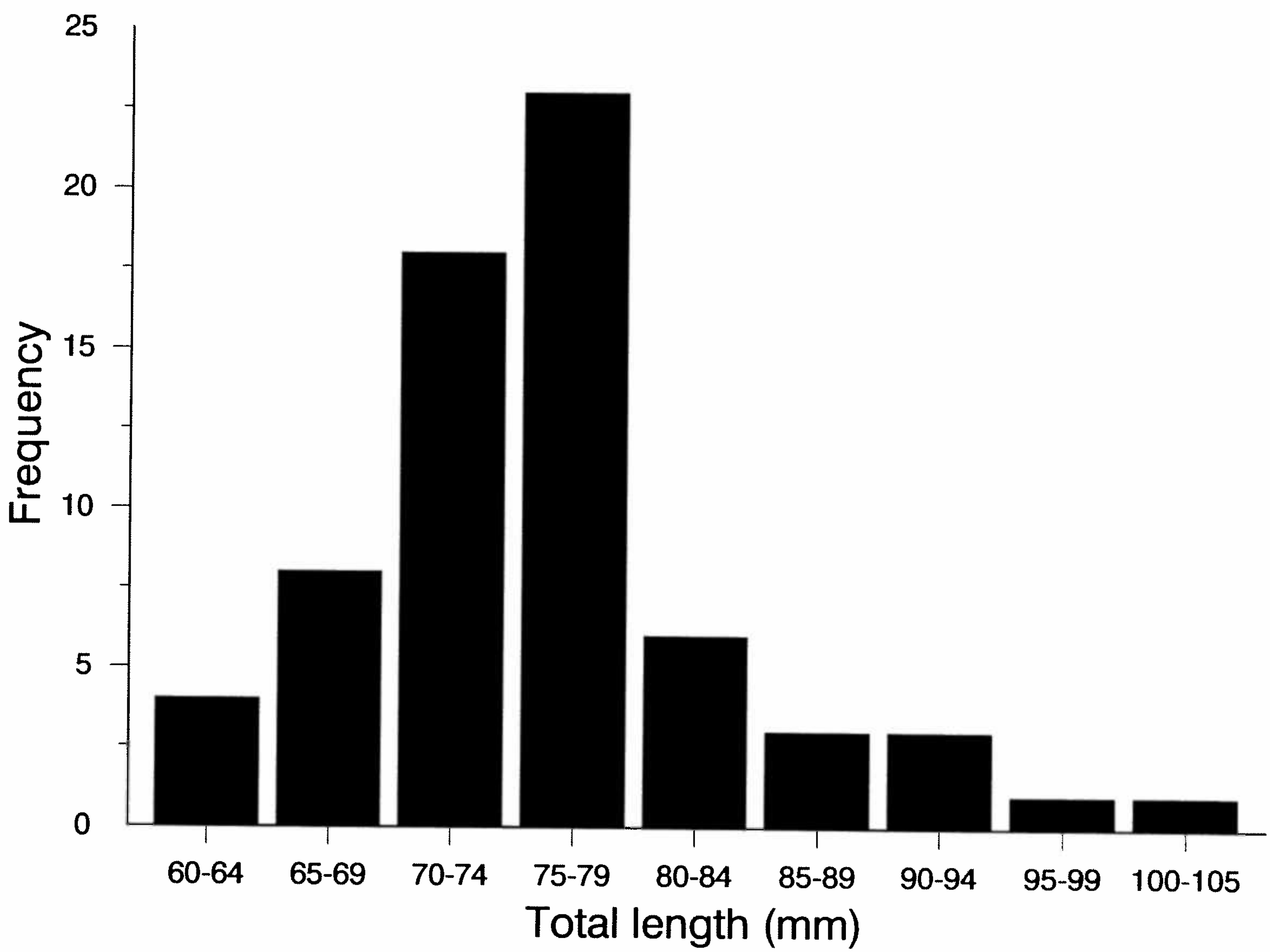

Figure 3.--Length-frequency histogram for largemouth bass captured by seining in the Fulton Ditch just downstream of the Parshall Flume, 2 September 1998.

Entrainment rate estimation

White sucker culture.--Average TL and mass for white sucker females was 460 mm and 2.85 kg, respectively. Average TL and mass for males was 430 mm and 2.34 kg, respectively. Average fecundity for the first group of white suckers we used was 36,839 eggs. Those eggs were taken in two batches 6 d apart; the first batch constituted about 68% of the total. A second group of similarly-sized female white suckers produced an average of 26,108 eggs in a single stripping. Circulating jars used to incubate white sucker embryos performed poorly because screens placed over flow outlets often clogged and jars nearly overflowed. Hatching success was estimated at < 10% and many of the few surviving larvae were either very small or deformed and in poor condition. Survival rates were assessed in Heath trays and mesh baskets at day five post-fertilization when eyes were pigmented and embryos were moving within the chorion. Survival of embryos in Heath trays averaged 69.8 %. Survival of embryos in baskets in each of two different troughs averaged 70.3 and 74.9 %.

Marking white sucker larvae.--Relatively few fish mortalities were noted during TC marking when fish density was held to about 50,000 larvae per trough. All fish died in one batch that was about four times that density, presumably due to reduced dissolved oxygen levels. Otoliths of 20 larvae were examined under 200x magnification and a fluorescent light source two days after marking. All larvae had fluorescent marks in their lapilli.

Field sampling to assess sediment trap efficiency.--Sediment trap discharge was similar on 30 April and 13 May even though ditch flows were quite different. On 30 April, about 47% (1.24 m^3/s) of diverted water was returned to the river and 53% (1.39 m^3/s) continued down the ditch. On 13 May, about 32% (1.32 m^3/s) of diverted water was returned to the river and 68% (2.75 m^3/s) continued down the ditch. The drift net sampled an average of 17.9 % (range 14.7 to 24.9 %) of the sediment trap return plume on each of the two test occasions. On 30 April, the average number of larvae returned to the river was 188 (range 166 to 209, 95% CI = 173 - 203) out of 1000. On 13 May, the average number of larvae returned to the river was 129 (range 75 to 199, 95% CI = 86 - 172) out of 1000.

Our null hypothesis for the 30 April test was that 470 larvae (expected number) should be returned to the river by sediment trap flows. On average, only 188 or 40% (188/470 = 39.88, ~ 40%) of the total expected to be returned did in fact go back to the river. Our null hypothesis for the 13 May test was that 320 or 32% of the larvae should be returned to the river by sediment trap flows. Again, only 129 or 40% (129/320 = 40.3, ~ 40%) of the expected number of larvae were returned. Therefore, based on two remarkably similar values obtained in different tests, sediment trap efficiency (*E*) was determined to be 40%. This suggested a net loss of larvae down the ditch that was far higher than we expected assuming that larvae should have been returned to the river in proportion to the amount of discharge returned.

Fish entrainment rates.--White sucker larvae were available in sufficient quantities to permit five releases (Table 2). In all, 382,556 marked larvae were released. Because downstream transport rates of larvae were unknown when sampling began, samples were collected continuously for about 18 hr after the first release of fish on 30 April. Sorting of several of those samples prior to fish releases on 12 and 14 May suggested that most (about 98%) fish were captured during the first two hr after release and that nearly all were captured after four to six hr (Table 3). Bead capture rates also declined soon after release and supported the contention that fish and beads moved through the system relatively quickly. Therefore, data used for calculation of entrainment rates was limited to samples collected four to six hr subsequent to a fish release.

A total of 188 drift net samples were collected. Of those, only 117 were used to calculate entrainment rates of larvae into Fulton Ditch because other samples were assumed to contain few or no fish. Samples were 3 to 4 L in volume and each took about 12 hr to sort. A total of 12,372 larvae were captured in those samples. Three of those were walleye larvae that were discussed above. The remainder were catostomid larvae.

We marked our white sucker larvae prior to release to be able to determine how many naturally produced larvae were captured in our nets. If large numbers of naturally produced fish were present, then both the expected and observed number of fish in the ditch would need to be adjusted. An average of 85% of otoliths from fish in samples were readable, and nearly all those otoliths had detectable marks (Table 4). The single fish from the first release on 14 May that did

Table 2.--River, ditch (at Parshall Flume), and sediment trap discharge (Q, in m^3/sec) on dates of fish and bead releases. The ratio is the proportion of ditch and sediment trap Q to the total diverted. Also presented are the total number of fish or beads (fish) released, the number captured in samples, the observed number of fish (that transported by the sampling station, which was estimated by: no. fish sampled/proportion of flow sampled), the total expected based on the proportion of water diverted and sediment trap efficiency (*E*), and the ratio of observed to expected numbers of fish captured. The number of beads captured and observed are identical because sampling was 100% efficient.

Date/release	River Q	Ditch Q	Sediment trap Q	Proportion of ditch, trap Q	# of fish released	# of fish captured	# of fish observed	# of fish expected	Ratio Obs./Expt.
Fish releases									
30 April (1)	51.3	1.39	1.24	0.53:0.47	53,600	285	843	2,283	0.37:1
12 May (1)	57.9	2.18	1.24	0.64:0.36	69,174	2,706	10,849	3,571	3.04:1
12 May (2)	61.3	2.83	1.24	0.70:0.30	69,174	2,348	11,584	4,118	2.81:1
14 May (1)	51.5	2.83	1.24	0.70:0.30	129,048	4,886	24,101	9,178	2.63:1
14 May (2)	55.4	2.83	1.24	0.70:0.30	61,560	2,144	10,427	4,059	2.57:1
				Totals =	382,556	12,369		Mean =	2.28:1
Bead releases									
27 October (1)	28.3	0.42	1.24	0.26:0.74	10,000	97	97	439	0.22:1
27 October (2)	27.0	0.42	1.24	0.26:0.74	10,000	697	697	463	1.51:1
27 October (3)	27.9	0.42	1.24	0.26:0.74	10,000	480	480	447	1.07:1
				Totals =	30,000	1,274		Mean =	0.93:1

Table 3.--Number of fish captured in successive two hr time intervals (time approximate) after each of five releases of white sucker larvae. Fish captures were the total for nine drift nets.

Date (Release)	Time post-release			
	2 hr	4 hr	6 hr	8 hr
30 April	278	6	1	0
12 May (1)	2,663	43	-	-
12 May (2)	2,312	36	-	-
14 May (1)	4,834	30	22	-
14 May (2)	1,897	221	26	-

Table 4.--Percentage of fish with readable otoliths and the percent of those that are tetracycline-marked. Fish were from samples collected in the two-hr period immediately after each of five releases of white sucker larvae.

Date (Release)	Number Examined	Number Readable	Number Marked
30 April	20	100%	100%
12 May (1)	20	60%	100%
12 May (2)	20	85%	100%
14 May (1)	20	85%	95%
14 May (2)	20	95%	100%

not have a detectable mark could either have been a wild fish or a cultured larvae that did not have a detectable mark.

Unreadable otoliths were opaque such that a mark would be impossible to detect and several shattered upon handling. Opaque otoliths were likely caused by the large amounts of debris in the samples, and the long time that lapsed between sample collection and sample processing. Most specimens were darkly stained with algal pigments mobilized by the ethanol preservative. Altered preservative chemistry may be responsible for reduced otolith clarity.

The ratio of observed numbers of fish to that expected at the site, which was based proportion of the river diverted and *E*, was used to evaluate entrainment rates. A proportion < 1 suggested that fish were entrained at rates lower than what was expected, a 1:1 relationship suggested that observed fish abundance was identical to that expected, and a ratio > 1 suggested that observed fish abundance was higher than expected.

The first release conducted on 30 April had a ratio of 0.37 and was the only one of the five that had an observed:expected ratio less than equality. During that low diversion rate release on 30 April 1998, we estimated that 1.5% of all fish released were entrained into Fulton Ditch even though we expected that 4.3% of all fish would be entrained. The remaining four releases on 12 to 14 May had an average observed:expected ratio of 2.76 (2.57 to 3.04; 95 % CI, 2.54 - 2.98). The average ratio suggested that approximately three times as many fish were captured in those four releases than were expected, based on the amount of river discharge diverted and *E*. At the higher ditch diversion rates experienced during the four releases on 12 and 14 May, we estimated that an average of 17.0% of all fish released were entrained into Fulton Ditch even though we expected only 6.2% to be entrained.

Fish capture rates were consistently higher in nets located on the outside of the ditch meander compared to those in the middle or on the other side of the ditch for all releases (Fig. 4). Even on 30 April, capture rates in nets declined substantially as distance from the outside meander bank increased. Lower fish density in the ditch during that release made the magnitude of reductions among the nets less apparent compared to other releases.

Bead entrainment rates.--Tests of bead sweep netting capture efficiency suggested that nearly every bead released in the ditch was captured. Releases of three successive lots of 500

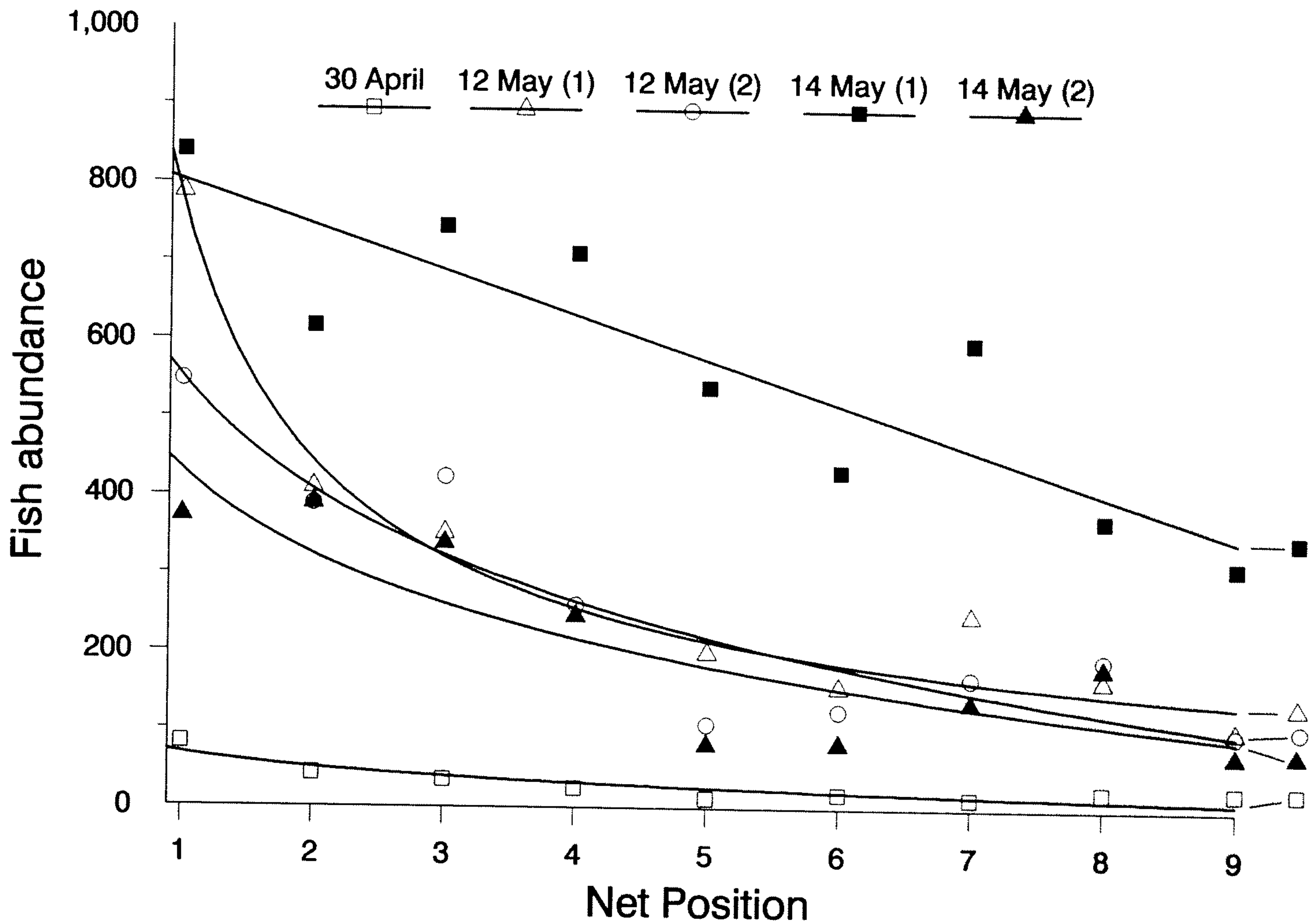

Figure 4.--Cross-channel abundance of fish captured in drift nets in the first two-hr sampling period after fish release. On 30 April, nets were set just under the surface and side-by-side beginning with net 1 on the outside (south) of the ditch meander just upstream of the Parshall flume. Nets were evenly distributed across the ditch during other releases. Abundance data fit with linear or non-linear regression functions had the following relationships: 30 April, $Y = 68.61 - 26.52*\ln X_1$, $r^2 = 0.79$; 12 May-release 1, $Y = 770.83*X_1^{-0.797}$, $r^2 = 0.89$; 12 May-release 2, $Y = 550.54 - 206.44*\ln X_1$, $r^2 = 0.85$; 14 May-release 1, $Y = 859.17 - 56.97*X_1$, $r^2 = 0.77$; 14 May-release 2, $Y = 432.25 - 155.70*\ln X_1$, $r^2 = 0.74$., where Y is estimated fish abundance and X_1 indicates net position. Symbols on the right margin associate individual data points with correct relationship.

beads each resulted in captures of 499, 534, and 468 beads; total bead captures were 1,501. We expected to capture a maximum of 500 beads on each occasion. The higher than expected number captured after the second release suggested that sampling was not discontinued soon enough and beads from the third release were inadvertently included. Notwithstanding, the total number released (estimated at 1500) and recaptured (N = 1501) suggested that no adjustments would be needed to calculate expected number of beads captured at the sampling station because capture efficiency was 100%.

Bead entrainment rates estimated on 27 October were also used to estimate the ratio of observed:expected numbers of beads captured. The average ratio for the three releases was 0.93 (individual ratios were 0.22, 1.51, and 1.07). The likely cause for the highly variable ratios was not allowing enough time between releases for captures to occur. Because sampling was extended well beyond the last release the overall mean probably represents a valid value. The ratio of 0.93 indicated that the observed number of beads captured was slightly less than what was expected, based on the amount of river discharge diverted and E.

Discussion

Fulton Ditch Fish Community Composition

Seining confirmed that South Platte River fish were entrained into Fulton Ditch. Because Fulton Ditch dries annually, the fish community present during sampling was necessarily recruited from either the South Platte River or Bull Seep. Similarities of the fish community up- and downstream of the flume, which is likely a barrier to upstream dispersal of most fishes from Bull Seep, suggested that the majority of canal fish were likely derived from the South Platte River. Most fishes were of sizes that corresponded to young-of-year and suggested that early life stages were transported from the river into the canal where they reared.

Species richness of the fish community of Fulton Ditch and Bull Seep was surprisingly high and one native species that was considered somewhat rare in Colorado, Iowa darter, was collected. Abundance of some species was uneven in the two habitats. For example, black bullhead, brook stickleback, and Iowa darter were most common in Bull Seep and were uncommon or absent in Fulton Ditch upstream of the flume. This suggested that the pool in Bull Seep, or upstream habitat was the source for some individuals that dispersed into the canal. In general, brook stickleback and Iowa darter in Colorado are most abundant in cool, clear, spring-fed streams (Bestgen 1989) like Bull Seep, which further supported the idea that individuals of those species found in the canal may have dispersed from there.

Absence of large individuals of any fish species in Fulton Ditch suggested that they were able to avoid entrainment from the river into the ditch. Presence of large numbers of adult carp observed in the river in the vicinity of the diversion dam supported the idea that few adult fish were entrained. Fish abundance was very low at the downstream 104th Ave. site and in the lateral. This suggested that most entrained fish either stopped movement down the canal shortly after being entrained, or were carried much further downstream.

The occurrence of walleye larvae in samples collected during the 30 April fish release suggested that most other South Platte River fishes had probably not yet reproduced because walleye are early season spawners (Corbett and Powles 1986, Johnston et al. 1995). White sucker may begin reproduction toward the end of the reproductive season of walleye (Geen et al.

1966, Corbett and Powles 1986). The extremely low occurrence of unmarked white sucker larvae (N = 1) in our drift samples collected on 30 April-1 May and 12 to 14 May suggested that all white suckers captured were ones that we released. It is possible that both walleye and spottail shiner could be vagrants from upstream Chatfield Reservoir or other reservoirs, where both species are known to reproduce. Natural reproduction by walleye in the South Platte or its tributaries can not be completely discounted, although abundance of adult-sized specimens in South Platte River electrofishing samples were non-existent (T. Harris, pers. comm.).

Entrainment rate estimation

Fish culture.--Use of cultured fish allowed us to concentrate sampling effort when larvae were known to be in the river and made the sampling design relatively efficient. The culture techniques we used were quite successful and allowed us to produce relatively large quantities of white sucker larvae. Fertilization success exceeded 90% and embryo survival to just before hatching was 70 to 75% when Heath trays or hatching baskets were used. Circulating jars are not recommended because hatching success was < 10% and the few surviving larvae were small or abnormal.

Fish marking.--Marking of larvae by immersion in a TC solution of 350 mg/L was successful at relatively low fish densities of 50,000/trough; few mortalities were observed and all fish were marked. Marking fish at higher densities may be possible if adequate levels of dissolved oxygen can be maintained. We also recommend that several days lapse between marking and release to ensure that the mark is not on the otolith margin.

Marking the larvae we used in release experiments allowed us to identify how many of the fish captured in ditch samples were ones that we released. Because only a single fish that had a readable otolith was not marked in the subsamples examined, we assumed that all fish captured were ones that we released. This assumption was supported by dramatic declines in capture rates of marked larvae within 4 hr after their release, a situation which would not be expected if substantial numbers of naturally produced larvae were present. This greatly simplified our analysis because not all fish had to be examined for marks and because we were able to assume that no naturally produced sucker larvae were present in the system. Thus, no adjustments were necessary to the expected and observed numbers of fish captured.

The substantial number of unreadable otoliths in fish may be due to the large amounts of debris fixed in the samples and to the long interval between sample collection and otolith analysis. Effects of different fixation and preservation routines with large amounts of organic debris would be a fruitful area for future research, given the importance of accurate detection of marks.

Field sampling to assess sediment trap efficiency.--Sediment trap efficiency to return fish to the river was much lower than we expected on both test occasions but reasons for low E are unknown. Nevertheless, we have confidence in the estimate of E because of remarkably similar test values. We also sampled a relatively large portion of the sediment trap flow (17 to 25%) and think the likelihood of uneven mixing of larvae in the turbulent, well-mixed water was low. Because efficiency tests were conducted under different ditch flows, we consider our estimate of E robust to environmental variation.

Entrainment rate estimation.--Results of this portion of the study also verified that fish larvae were entrained from the South Platte River into Fulton Ditch. The extremely high river flows forced us to change our sampling and release design to maximize our chances of capturing beads and fish larvae. Because fish and beads were released exclusively along the bank of the river where the Fulton Ditch headgate was located, entrainment and capture rates were expected to be the highest ones possible.

Sampling data from five releases of fish suggested that rates of fish entrainment were lower than expected on one occasion and higher on the other four. On 30 April when fish captures were lower than expected, canal flows were also relatively low. It may be that at relatively low diversion rates, a disproportionately larger number of larvae were transported downstream past the ditch headgate. No other plausible reasons for the lower entrainment rate on 30 April were apparent. River discharge was similar to that on other releases, as was time and location of release, water temperature and clarity, and the number and age of fish released. On the four subsequent releases, observed number of fish captured was about three times higher than that expected. During the first release on 12 May, ditch flows were 30% higher than on 30 April.

During the second release on 12 May, and first and second releases on 14 May ditch flows were 55% higher than on 30 April.

There are at least two obvious reasons why observed fish capture rates were higher than those expected. The first and most important reason is that the expected fish number was calculated based on the assumption that all larvae were evenly distributed across the river channel. That was not the case since all larvae were released on the side of the river where the headgate was located. Observations of beads as they approached the diversion dam after release suggested that most were circling in the eddy upstream of the diversion dam rather than passing downstream. Thus, beads had at least one opportunity to be swept by the headgate and entrained into the ditch before they continued downstream. If fish were similarly distributed, nearly all larvae would have at least one chance to be entrained into the canal before continuing downstream. If larvae were evenly distributed across the channel, it is likely that only a third to a half of them may be susceptible to entrainment and the rest would simply pass downstream.

Another potential reason why observed fish abundance was much higher than expected abundance in four of five releases may be due to the cross-channel distribution of fish in the ditch channel (Fig. 4). Larvae that are relatively weak-swimming might be expected to occur at higher densities near the outside of a channel meander where current velocities were higher. This was supported by observations of the distribution of drifting beads during sweep netting, where bead density was approximately twice as high within about 1.5 m of the outside meander bank than on the opposite bank. Larvae may also be concentrated on that bank because they are attempting to visually orient to it in order to hold a position. Regardless of the reason for cross-channel distribution patterns, fish captures may have been biased high because a relatively large portion of the high-density fish area was sampled by the two nets nearest the shore.

Because we calculated expected fish abundance as if fish were evenly distributed in the river and in the canal, the observed fish abundance estimates were likely biased high. Suitable adjustment factors to entrainment rates need to be used when the significance of fish entrainment into Fulton Ditch is discussed.

Sampling of naturally produced fish larvae in other river systems has also demonstrated spatial and temporal variation in distribution of drifting fishes (Geen et al. 1966, Clifford 1972, Gale and Mohr 1978, Gerlach and Kahnle 1981, Armstrong and Brown 1983, Gallagher and Conner 1983, Muth and Schmulbach 1984, Corbett and Powles 1986, Franzin and Harbicht 1992, Bestgen et al. 1998). Catostomids and cyprinids, which make up the bulk of the species that reside in the South Platte River, typically drift as larvae in greatest abundance at night and near the surface. The main explanations for such patterns are loss of orientation in the dark, predator avoidance, or negative phototactism. Density of drifting larval fishes has been described as homogeneous across the channel or concentrated nearshore, but those patterns are not well-known. River hydraulics and water velocity, habitat features, proximity to spawning areas, and fish size, age, and behavior are but a few of the factors that may influence horizontal, as well as vertical and diel distribution and abundance patterns of drifting larval fishes. These factors, coupled with knowledge of timing of reproduction, can be used to assess the likelihood and magnitude of fish entrainment into Fulton Ditch.

Bead entrainment rates.--Bead capture rates in the canal were slightly less than what was expected. Expected capture rates were calculated based on the assumption of a homogenous distribution of beads across the river channel, which of course was not the case because bead releases were made only on the side of the river where the headgate was located. Similar to fish larvae, beads had at least one and perhaps several chances to be entrained because most released beads were captured in the eddy upstream of the canal headgate. Thus, a main conclusion from bead release experiments is that although beads were entrained at rates about equal to that expected, bead capture rates would be much lower than expected if beads had been released evenly across the river. The lower than expected capture rates for beads during this experiment and for fish larvae on the 30 April release suggested that entrainment of fish larvae may be disproportionately low when canal diversion rates are low.

Uncertainties.--Several uncertainties remain regarding estimation of entrainment rates of fishes into Fulton Ditch during 1998. First, it is unknown how the relatively high river flows during spring and summer, especially relative to the amount of water diverted, affected fish community composition and abundance and fish entrainment rates during releases. If a greater proportion of the river had been diverted into the ditch, species richness and fish entrainment rates may have been higher. Further, entrainment rates may also have been enhanced because most of the river would have been flowing along the east bank where the ditch headgate occurs. Alternatively, entrainment rates may also be reduced in a low-water year because larvae may be able to maintain positions in the low-velocity pool upstream of the diversion dam. Only additional fish releases and entrainment rate estimation when discharge is lower will resolve these questions.

A second uncertainty is what the distribution and composition of naturally produced fish larvae is in the river, especially at different times of the year. During this study we maximized fish entrainment and capture rates because high water forced release of all fish along the east bank where the headgate occurred. If larvae are distributed approximately equally across the river, entrainment rates and the ratio of observed:expected fish abundance may be much lower. Cross-channel distribution of larvae could be estimated either by capture of naturally occurring or marking and releasing larvae. Such information could be used to scale down the entrainment rates estimated in this study by an appropriate amount.

A third uncertainty is the accuracy and precision of drift-net sampling to estimate observed fish abundance in the ditch. Even with nine nets, we sampled only 1/5 to 1/3 of the total ditch discharge. Releases of known quantities of marked larvae in the ditch downstream of the sediment trap, similar to what was done with beads, may give insights into the cross-channel and vertical distribution of drifting larvae. That information could be used to determine the adequacy of the sampling approach used in this study. All of these topics are worthy of further investigation.

Management considerations

Results of this study quantified the species composition and relative abundance of fishes in Fulton Ditch. Species richness and fish abundance of the Fulton Ditch fish community was relatively high near the diversion but declined quickly downstream. The most common species collected were native fathead minnow and white sucker, both of which were abundant in the South Platte River. White sucker abundance in Fulton Ditch may have been particularly high in 1998 because some of our released fish likely survived in the ditch. The only rare native species captured in the ditch, Iowa darter, likely originated from habitat in tributary Bull Seep. Other rare native species are unlikely to be affected by entrainment because they are unlikely to occur in the degraded South Platte River habitat. The most abundant non-native species, largemouth bass, is an important component in recreational fisheries in lentic habitats. However, that species would be unlikely to establish a viable fishery in the river because of lack of suitable adult habitat. Thus, it is unlikely that fish entrainment into Fulton Ditch reduced species richness of the fish community of the South Platte River.

Entrainment rates of larvae appeared to be dependent upon diversion rates. At low rates of diversion, bead and fish release data suggested that few fish were entrained and at rates that were lower than expected. During the single 30 April release, we estimated that 1.5% of all fish released were entrained into Fulton Ditch even though we expected that 4.3% of all fish would be entrained. Thus, entrainment rates were nearly three times lower than we expected. At higher ditch diversion rates, entrainment rates were higher than expected. During the remaining four releases on 12 and 14 May, we estimated that an average of 17.0% of all fish released were entrained into Fulton Ditch even though we expected only 6.2% to be entrained. This was likely due to release of fish exclusively on the bank where the headgate occurred and concentration of sampling in areas of the ditch where larvae were concentrated. After accounting for those potential biases, we hypothesized that entrainment rates during periods of high ditch diversion rates were probably proportional to water diversion rates. Thus, the importance of entrainment loss to Fulton Ditch may be species-specific and depend on the timing of appearance of larvae relative to overall river discharge and rates of diversion. It is expected that the most severe impacts would occur in summer when river discharge is low and ditch diversions are high.

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Appendix I. List of common and scientific names of fishes captured during this study.

Common Name	Scientific Name
common carp	*Cyprinus carpio*
golden shiner	*Notemigonus crysoleucas*
spottail shiner	*Notropis hudsonius*
sand shiner	*Notropis stramineus*
fathead minnow	*Pimephales promelas*
longnose sucker	*Catostomus catostomus*
white sucker	*Catostomus commersoni*
black bullhead	*Amieurus melas*
brook stickleback	*Culea inconstans*
western mosquitofish	*Gambusia affinis*
green sunfish	*Lepomis cyanellus*
bluegill	*Lepomis macrochirus*
largemouth bass	*Micropterus salmoides*
black crappie	*Pomoxis nigromaculatus*
Iowa darter	*Etheostoma exile*
yellow perch	*Perca flavescens*
walleye	*Stizostedion vitreum*