Distribution, Migration Behavior, Habitat Use, and Species Interactions of Fall-Released Juvenile Hatchery Spring Chinook Salmon on the Deschutes River, Oregon, 2002

Annual Report for 2002

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Distribution, Migration Behavior, Habitat Use, and Species Interactions of Fall-Released Juvenile Hatchery Spring Chinook Salmon on the Deschutes River, Oregon, 2002

Annual report for 2002

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Executive Summary

In a review of National Fish Hatcheries (NFH), the U.S. Fish and Wildlife Service (USFWS) identified the need to assess the fate of hatchery-reared fish and their potential effect on the aquatic community (USFWS 1998). Additionally, in the Columbia River Biological Opinion, the National Marine Fisheries Service (NMFS) recommended monitoring and evaluating ecological interactions between hatchery and wild fish (NMFS 1999). In 2002, a study was designed to investigate the fate of hatchery-reared fish and to assess habitat use and fish interactions in the Deschutes River, Oregon.

In this study, we used biotelemetry to examine the distribution and behavior of fall-released juvenile hatchery spring Chinook salmon in the Deschutes River. From 2 November, 2002 to 7 February, 2003 we radio tagged and tracked 24 fish. Fish were surgically implanted with radio transmitters and released downstream of a migrant trap on the Warm Springs River. Four telemetry fixed sites were established along the lower Deschutes River and two telemetry fixed sites were used on the Columbia River to monitor fish movement after leaving the Deschutes River. Based on data obtained from fish implanted with 90-d tags, we found that 37.5% (3 of 8) of the radio-tagged fish left the Deschutes River and 62.5% (5 of 8) remained in the Deschutes River. Fish that left the Deschutes River migrated quickly and exited the 135 km study area in a median travel rate of 0.49 km/h and total travel time of 66.1 h (2.75 d). Once fish left the Deschutes River they were not detected in the Columbia River. A smaller transmitter with 9 d life expectancy was used to gain information on smaller fish. Based on data obtained from smaller fish, we found that 7% (1 of 14) of the radio-tagged fish left the Deschutes River and 93% (13 of 14) remained in the Deschutes River during the life of the tag (9 d). The fish that left the Deschutes River migrated quickly and exited the 135-km study area with a travel rate of 0.60 km/h. Although our sample size was small, it appears that larger fish were more likely to leave the Deschutes River. These findings suggest that the fall-released fish have a potential to overwinter and their impact on the aquatic community could negatively effect the wild fish population.

From 15 November 2002 through 20 January 2003, Confederated Tribes of Warm Springs Reservation, OR (CTWSRO) and U.S. Geological Survey (USGS) personnel mobile tracked radio-tagged juvenile Chinook salmon in the Deschutes River. We were

able to collect multiple contacts on 13 of the 18 fish that remained in the river and determine holding areas. All fish with a 90 d tag remaining in the Deschutes held in the lower portion of the study area, below Oak Springs. Once a fish stopped migrating downstream, it remained in that general location. Most mobile contacts of fish tagged with 9-d tags were made in the upper portion of our study area, above Oak Springs.

ATPase activity was measured as an indicator to better understand the physiological development of fish that leave the Warm Springs National Fish Hatchery during the fall volitional release. Thirty fish were sampled from each of nine volitional release ponds. ATPase levels were not related to size at the hatchery ($R^2 = 0.0006$), and samples were not taken in 2002 at the migrant trap, due to a lack of available fish.

We wanted to determine the feasibility of using PIT-tag technology to determine distribution of juvenile Chinook salmon after their volitional release in fall from the Warm Springs NFH. Because of their small size (12 mm in length), PIT tags can be inserted in much smaller fish than radio tags and would allow us to monitor fish in a smaller size category. We inserted 723 PIT tags into hatchery Chinook salmon that were caught at the fish trap. To detect PIT-tagged fish in a free-flowing stream, we constructed a portable unit consisting of a PIT-tag transceiver and an antenna. During three raft trips, radio/PIT tagged fish were located with radio telemetry but no PIT-tagged fish were detected.

A literature review was conducted on behavioral interaction studies of juvenile salmonids. We were asked to review the relevant literature on behavioral interactions between various species of salmonids, with an emphasis on the influence of hatchery spring Chinook salmon on other fish. The review describes the types of interaction studies that have been done and the various experimental systems that have been used to conduct such studies. Included is a discussion of the advantages, disadvantages, and design considerations of the various experimental systems (e.g., aquaria, mesocosms, in-stream enclosures) used in the studies. The studies we reviewed covered a wide range of species and experimental designs from the 1950's to the present. In total, we reviewed over 100 manuscripts. Of these, 43 met the criteria for inclusion into this review.

Chapter 1

Distribution, Migration Behavior, Habitat Use, and Species Interactions of Fall-Released Juvenile Hatchery Spring Chinook Salmon on the Deschutes River, Oregon

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Introduction

The U.S. Fish and Wildlife Service's (USFWS) review of National Fish Hatcheries (NFH) practices identified a need to assess the fate of hatchery-reared fish and their potential effect on the aquatic community (USFWS 1998). Additionally, the National Marine Fisheries Service (NMFS) recommended monitoring and evaluation of ecological interactions between hatchery and wild fish (NMFS 1999; Columbia River Biological Opinion). In response to these recommendations and findings, the U.S. Geological Survey (USGS) conducted a pilot study in 2000 in cooperation with USFWS and the Confederated Tribes of Warm Springs Reservation, Oregon (CTWSRO), designed to investigate the potential effect of hatchery-reared fish released from the Warm Springs National Fish Hatchery (NFH) on the aquatic community in the Deschutes River (Wardell 2002). Results of this pilot study indicated that the methods were feasible and appropriate, which prompted interest in funding additional research. In 2002, a study was designed to investigate the fate of hatchery-reared fish and to assess habitat use and fish interactions.

Warm Springs NFH is a unique program in the Columbia River Basin. The operation of the hatchery is considered pivotal for enhancing salmon stocks to meet tribal trust responsibilities**,** and it is managed to preserve the genetic integrity and characteristics of hatchery and wild fish. Managers are concerned about fall releases of juvenile spring Chinook salmon because hatchery fish that over-winter in the Warm Springs and Deschutes rivers may negatively interact with wild fish. However, quantifying the freshwater fate of juvenile Chinook salmon, *Oncorhynchus tshawytscha,* released in the fall from Warm Springs NFH has been problematic (Olson et al. 1995). Typically, about 10% of the hatchery production volitionally exits the hatchery in the fall (30,000 to 75,000 fish). In the past, this fall emigration (early October - early November) included a mixture of sizes, ranging from 70 mm to 229 mm, with the majority of fish being 140 mm or larger (USFWS 1999). Most fish released in the spring reach the Columbia River estuary within 3-4 weeks of release, whereas the movement and fate of fish volitionally released in the fall was not clear. Cates (1992) reported that fish from the fall release survive and contribute to adult production. Sampling in the lower Deschutes River, at Bonneville Dam, and in the Columbia River estuary indicated that

fish released in the fall can exit the Deschutes River during the fall, winter, or spring periods. Recent scale analysis has shown that most fall-released fish surviving to adulthood have over-wintered in freshwater before migrating to the ocean in the spring (J.Fryer, Columbia River Inter-Tribal Fish Commission, personal communication). Although the fall volitional release strategy has been successful in contributing to adult returns (Olson 1998), managers are concerned that large numbers of hatchery fish rearing in the Deschutes River may negatively affect the freshwater aquatic community. These over-wintering hatchery salmon could displace or compete with wild fish in the Deschutes River.

In 2000, we conducted a pilot study to determine the distribution of fall-released fish in the Deschutes River and investigate methods to assess habitat use. Fifty-four fish were implanted with radio transmitters and tracked for 45-75 d. Over the study period, we found that 65% of the radio-tagged fish remained in the Deschutes River, indicating that there were a substantial number of fish remaining over the winter. With the majority of fish remaining in the river, there could be a potential impact on wild juvenile spring Chinook salmon, bull trout (*Salvelinus confluentus*), steelhead, rainbow trout (*Oncorhynchus mykiss*), and other resident fish. Habitat assessments conducted during the pilot study at sites where radio-tagged fish were found indicated that these fish select discrete microhabitat. If there is interspecies overlap in microhabitat use and potential antagonistic behavior caused by hatchery-released fish, then managers may need to review current practices. However, if there are low levels of interaction or overlap in microhabitat use, the hatchery-released fish may be able to coexist in the Deschutes River.

Our work in 2002 was intended to expand the work conducted in 2000 and further develop the habitat and ecological interactions assessment. The objectives of this study were to: 1) determine the over-wintering behavior and distribution of fall volitional releases of juvenile hatchery spring Chinook salmon in the Deschutes River using radio telemetry; 2) determine the migration behavior of fish that leave the Deschutes River system and enter the Columbia River; 3) assess the feasibility of using Passive Integrated Transponders (PIT) tag technology to determine distribution of juvenile hatchery spring Chinook salmon in the Deschutes River; 4) investigate techniques to determine hatchery

Chinook interactions among and between other species during the winter; and 5) conduct a literature review of behavioral interaction studies of juvenile salmonids (Chapter 2 of this report). The results of this study, along with future studies, will help fisheries managers determine the potential impact of hatchery release strategies on the aquatic community within the Lower Deschutes watershed.

Methods

Study site

Warm Springs National Fish Hatchery is operated by the USFWS and is located on the Warm Springs River, within the Warm Springs Indian Reservation of Oregon. The Warm Springs River is a major tributary to the lower Deschutes River in north central Oregon and enters the Deschutes River at river kilometer (Rkm) 135. The Deschutes River enters the Columbia River 330 km from the Pacific Ocean (Figure 1).

Migrant Trap

An eight-foot rotary screw trap was installed near the mouth of the Warm Springs River, about 10 kilometers downstream of the Warm Springs NFH, by CTWSRO staff, to monitor wild and hatchery spring Chinook salmon movement. The trap was operated from 26 September to 20 December, 2002. This trap was moved to an old bridge abutment upstream from the Heath Bridge, and replaced a Humphrey scoop trap that was used for over 25 years. The trap was typically operated 24 h/d, Monday through Friday. Fish caught in the trap were identified and enumerated. A sub-sample of up to 20 each steelhead/rainbow trout, bull trout, wild Chinook, hatchery Chinook, and lamprey was measured per day. CTWSRO staff marked, with a fin clip to the upper or lower caudal, bull trout, steelhead/rainbow trout, wild spring Chinook, and hatchery spring Chinook to perform population abundance estimates. CTWSRO and USFWS produced population estimates and calculated trap efficiencies based on trap data.

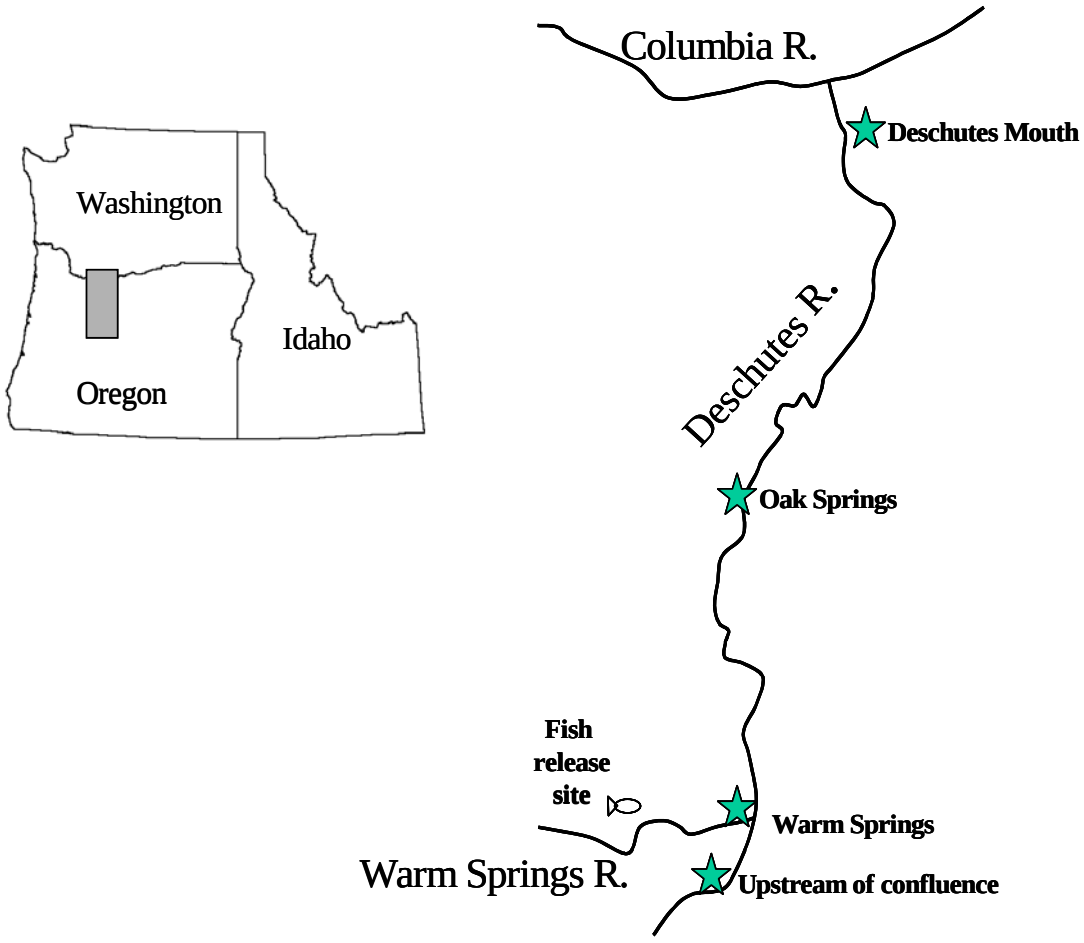


Figure 1—Map of Lower Deschutes River, Oregon, showing study area, fixed monitoring telemetry sites (stars), and release site of radio-tagged juvenile Chinook salmon in 2002.

Radio Tagging & Transmitters

Juvenile Chinook salmon used in our study were collected in the downstream migrant trap in the Warm Springs River operated by CTWSRO. Fish were collected by CTWSRO personnel and held in containers (127 L) in the river for at least 24 h prior to tagging. Fish were surgically implanted with microprocessor coded radio transmitters using procedures described by Adams et al. (1998). Biological measurements including fork length, weight, and overall condition were recorded for all radio-tagged fish.

We selected specific radio transmitters to meet this study's objectives. Initially, one model of digitally-coded radio transmitter was used (Lotek Engineering; model NTC-4-2L), having a 7 s signal burst interval, a mean weight of 2.0 g, and a battery life of 90 d (Table 1). In order to have transmitters that were comparable to the 2000 study, half of these transmitters were modified by removing excess epoxy encapsulating material to a mean weight of 1.7 g (medium tag). All transmitters were given a 24 h water test to ensure that the tag was operating. When average fish size at the hatchery was determined to be smaller than previous years, an additional transmitter was later added and used in the study. This digitally-coded transmitter (Lotek Engineering; model NTC-3-1) had a 2 s signal burst interval, a battery life of 9 d, and a mean weight of .85 g. Although the tag life was only 9 d, the smaller size of the tag allowed us to gain some insight into the migration behavior of smaller fish. All transmitters had a unique channel-code combination so that we could distinguish individual fish. Transmitter size was determined based on a maximum 5% tag weight to fish weight ratio. To achieve this ratio, larger transmitters (2.0 g) were implanted in fish >44 g (estimated >155 mm FL). The medium sized tags (1.7 g) were implanted in fish 33-44 g (estimated 135-155 mm FL). The smaller 9-d tags (.85 g) were implanted in fish 23-32 g (estimated 120-134 mm). We did not tag fish smaller than 120 mm FL. Immediately after tagging, fish were placed in a recovery container (127 L) supplied with a constant flow of river water and bottled oxygen. After about 30 min in the recovery container, fish were transferred to holding containers and held for 24 h in the Warm Springs River before release. Immediately before release, transmitters were checked to ensure that they were functioning properly.

Table 1—Specifications for transmitters implanted in juvenile Chinook salmon in the Deschutes River, 2002. Specifications supplied by manufacturer (Lotek Engineering, Ontario, Canada). Asterisk (*) indicates that tag was modified post-manufacturing.

Transmitter type	Dimensions (mm)	Weight (g)	Burst rate (s)	Battery life (days)
Large	16.5 x 6.3	2.0	7	90
Medium*	16.5 x 6.3	1.7	7	90
Small	14.5 x 6.3	0.85	2	9

Fixed-Site Monitoring

Four telemetry fixed sites were established along the lower Deschutes River (Figure 1). The first site was located near the mouth of the Warm Springs River and monitored fish as they migrated out of the Warm Spring River and entered the Deschutes River (Rkm 135). The second site, located near Oak Springs Fish Hatchery (Rkm 76), served as a midway point between the Warm Springs River and the mouth of the Deschutes River. The third site, near the mouth of the Deschutes River (Rkm 2), monitored fish as they left the Deschutes River system and entered the Columbia River. The fourth site, new in 2002, was upstream of the confluence with the Warm Springs River and was established to help us monitor upstream movements once fish entered the Deschutes River. Fixed stations consisted of two four-element Yagi (aerial) antennas mounted on a 6 m mast and connected to Lotek SRX 400 data-logging receivers (Lotek Wireless, Ontario, Canada). Each station was powered by 12 V deep-cycle batteries connected to solar powered chargers. To minimize the time required to monitor channel-code combinations, four channels were chosen. To ensure sufficient time for the receiver to recognize and log the signal, each channel (frequency) was monitored for 8 s before moving to the next channel. This resulted in a 24 s scan time. Data were collected on telemetry receivers continuously. Sites were maintained and data downloaded to a hand-held or laptop computer on a weekly basis.

Two existing USGS telemetry receiving arrays were also used along the lower Columbia River, allowing us to monitor fish that left the Deschutes River and migrated downstream. The first array, located in the Bonneville pool near Lyle, Washington (Rkm 286.1), was set up similar to that on the Deschutes River. The second array consisted of

70 antennas, spanning across Interstate-205 Bridge near Portland, OR (Rkm 181). Sites were maintained and data downloaded to a hand-held or laptop computer on a weekly basis.

Mobile Tracking

To determine the location and spatial distribution of radio-tagged juvenile Chinook salmon, as well as to verify data from fixed sites, mobile tracking was conducted in the lower 135 km stretch of the Deschutes River on a weekly basis. CTWSRO and USGS personnel mobile tracked radio-tagged fish using vehicles equipped with a telemetry antenna and receiver between 0800 and 1600 hours. When a radio-tagged fish was located, a global positioning system (GPS) unit was used to georeference the position. Fish locations were also marked on a map, along with the time and a written description of the general area. Once a fish was found repeatedly in a discrete location for more than two weeks, we considered that the fish was holding. We then pinpointed its location and were able to describe the physical habitat.

Radio Telemetry Data Management and Analysis

Data collection began on 2 November 2002 and continued until 7 February 2003 when the life expectancy of the transmitters was surpassed. Data were incorporated into a statistical analysis software (SAS version 8.1) and automatically proofed. Automated proofing was followed by manual proofing to ensure the quality of all data. All fish records were scrutinized to determine fish presence at each fixed site.

We calculated the travel times and travel rates of fish between detections at the fixed sites. Travel times were calculated as the time taken to travel from the upstream site to the next downstream site. Travel rates were calculated by dividing the distance traveled by the travel time. Travel times and rates were investigated relative to fish length, weight, and condition factor. All statistical tests were conducted at the 5% probability level.

Migration behavior and distribution were reported for fish implanted with the 90-d transmitter. The smaller 9-d tags were used as a supplement to the larger fish (90-d tag)

and were limited to only 8 d of monitoring. Therefore, results from fish implanted with the 9-d tag are reported separate from the results from the fish implanted with the larger 90-d tag.

River Conditions

Daily stream flow data was obtained from USGS gaging stations along the lower Deschutes River, at Moody (Rkm 2.5), and on the Warm Springs River, at Kahneeta (Rkm 10). Temperature data was also available from Portland general electric (PGE) thermagraphs on the lower Deschutes River at Ferry Canyon (Rkm 40; site 32) and Kaskela (Rkm 127; site 29).

ATPase Sampling and Analysis

Gill Na^+,K^+-ATPase (hereafter referred to as ATPase) activity has commonly been used as an indicator of physiological development of anadromous salmonids during the parr-smolt transformation (Ewing 1984) and for smolt condition assessment (Folmar 1980; Dickhoff 1995; Beckman et al. 1999). Elevated levels of ATPase are typically correlated with seaward migration of Chinook salmon (Hart et al. 1981). We measured ATPase activity as an indicator to better understand the physiological development of fish that leave the Warm Springs National Fish Hatchery during the fall volitional release. Fish size is usually positively correlated with ATPase activities (Folmar 1981). Because the sizes of fish leaving the hatchery during the fall volitional release are substantially larger than the fish remaining at the hatchery (Cates, U.S. Fish and Wildlife, unpublished data), we hypothesized that fish that leave volitionally should have higher ATPase levels than those smaller fish that remain in the hatchery. We planned to sample ATPase from fish at the Warm Springs National Fish Hatchery on two separate occasions; Pre-release at the hatchery, on 2 October, and at the migrant trap during migration of the fall volitional releases.

Pre-release sampling was conducted during the annual fish health screening at Warm Springs National Fish Hatchery. We sampled from volitional release ponds in conjunction with the fish health screening, collecting length and weight measurements as well as gill clips. We sampled 30 fish from each of nine volitional release ponds: Ponds

5, 6, 7 (Spring/Fall Erythromycin treated), ponds 8, 9, 10 (Spring Erythromycin treated), and ponds 25, 26, and 27 (control), for a total of 270 samples. ATPase analysis was conducted using procedures described by Schrock et al. (1994). Condition factor was also calculated and Gill Na+, K+ -ATPase activity was compared to fork length.

We planned to sample 90 hatchery fish that were collected in the downstream migrant trap. ATPase samples were to be collected during the fall migration, and coincided with our radio tagging of juvenile Chinook salmon. The sampling strategy at the trap included non-lethal sampling of 30 fish from each radio tag category as described above. Non-lethal ATPase sampling techniques were to be used to determine physiological condition of migrating fish. Fish that were sampled for ATPase were of similar size to radio tagged fish but not implanted with transmitters, so as not to introduce additional variation.

PIT Tagging

We inserted PIT tags into the abdominal cavity of hatchery spring Chinook that were caught at the fish trap. All PIT tags used were 12-mm, 134.2 kHz, which met the requirements for use of PIT tags in the Columbia River Basin as documented by the Columbia Basin Fish and Wildlife Authority (1999), and our procedure for PIT-tagging fish followed the procedures and guidelines outlined in that document. To ensure highest possible survival, the minimum size of fish to be tagged was set at 80 mm. The PIT-tag number and associated data on fish description and tagging location were sent to Pacific States Marine Fisheries Service for incorporation in the Columbia River Basin's PTAGIS database so that the PIT tag was properly registered and data on future detections from other sources could be retrieved.

Based on the size distribution during the first few weeks in 2002, we selected three size classes: <115 mm, 115-134 mm, >134 mm. We then planned to PIT tag fish in these size classes in a stratified approach with an emphasis on the smallest two size classes: 375 tags in each of the smallest two size classes and 250 tags in the largest size class.

Some of the PIT-tagged fish were also radio tagged. In order to maintain consistency of methods and fish treatment between 2000 and 2002, this double tagging

effort was restricted to a sub-sample that were implanted with a 9-d tag as well as a sub-sample (20%) of fish implanted with a 90-d radio tag. PIT tags were placed in the body cavity during radio-tag surgery.

Detecting PIT Tagged Fish in the Deschutes River

To detect PIT-tagged fish in a free-flowing stream, we constructed a portable unit consisting of a PIT-tag transceiver and an antenna. This unit was similar to that described in Zydlewski et al. (2003). Read range for detecting a standard 12-mm PIT tag was determined to be 15.2 – 25.4 cm from the loop of the antenna. In reaction to performance of the unit during trials, the unit was modified to maximize detection efficiency.

On 16 October 2002, a field trip was conducted on the White Salmon River (Washington) to determine the efficacy of the unit to detect fish from a raft in a large and fast-flowing river. We chose the White Salmon River because numerous rainbow trout were already PIT tagged, and some of these were also fitted with a radio tag, as part of an unrelated project. During the raft trip, a radio-tagged fish that was also PIT tagged was located with radio telemetry. Several attempts were made using the portable PIT tag reader while floating over the radio and PIT-tagged fish. The fish was not detected. As a result of this trial, changes were made in the antenna design to increase the read range of the portable unit before it was used on the Deschutes River.

Results

River Conditions

The Deschutes River is a relatively stable river (Deschutes River Subbasin Summary, 2001), primarily because the Pelton/Round Butte complex regulates daily outflow. Mean daily discharge remained relatively stable throughout the length of the study, ranging from 4,330 to 6,860 cfs (Figure 2). Temperatures on the Deschutes decreased from about 14 ^{o}C in early October to 6 ^{o}C in late January (Figure 3).

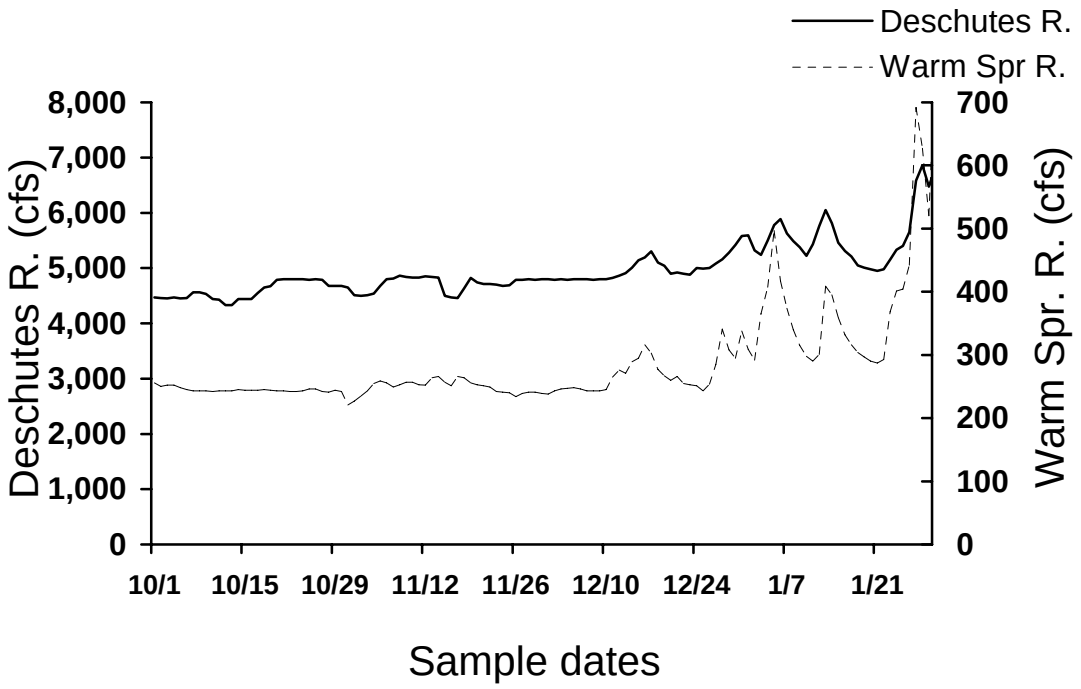


Figure 2—Mean daily discharge (cfs) from 1 October 2002 to 31 January 2003 on the Deschutes River (Rkm 2.5) and Warm Springs River (Rkm 10), Oregon.

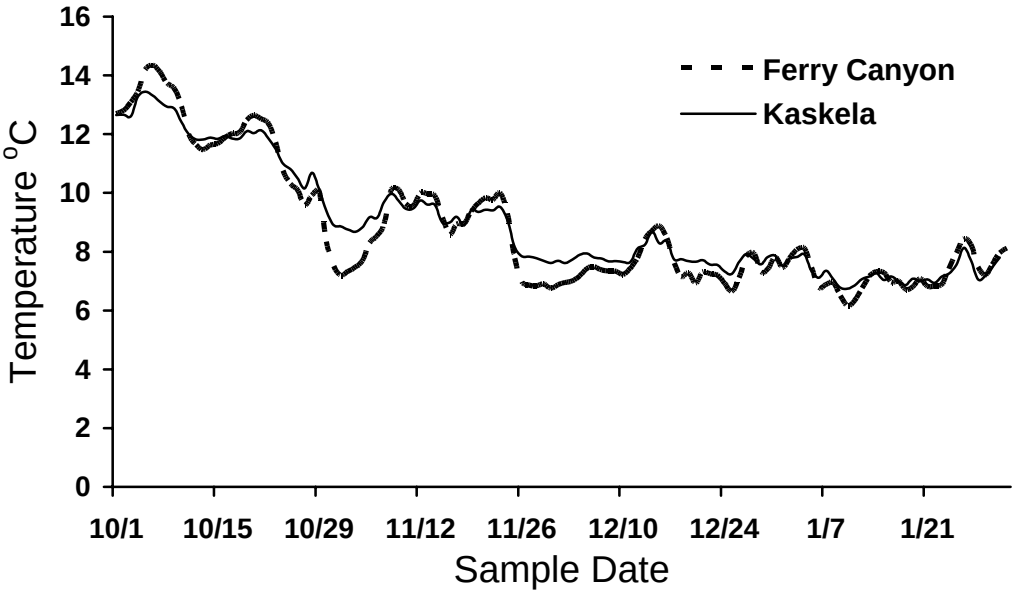


Figure 3—Mean daily river temperature (ºC) of the Lower Deschutes River between 1 October 2002 and 31 January 2003. Sample locations were at Kaskela (Rkm 127) and Ferry Canyon (Rkm 40). Data were collected by Portland General Electric.

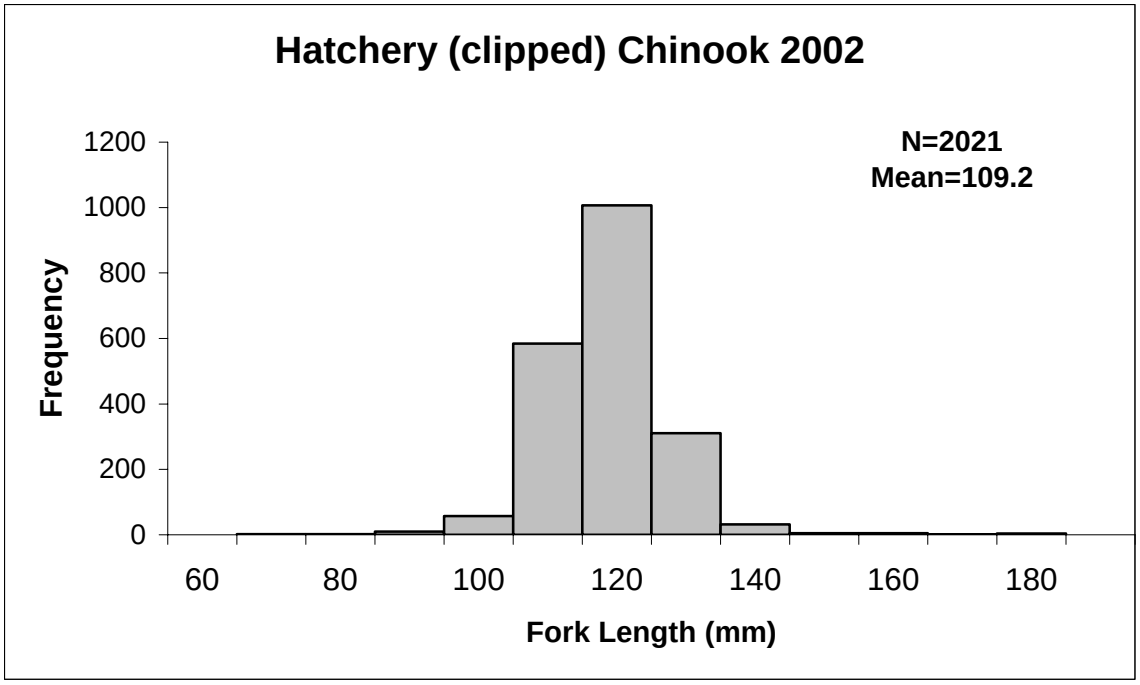
Migrant Trap

Hatchery fish collected at the Warm Springs downstream migrant trap between 11 October and 17 December were larger than their wild counterparts (Figure 4). The mean size of hatchery juvenile Chinook salmon was 109 mm and ranged from 60 to 171 mm. In comparison, the mean size of wild juvenile Chinook salmon was 83 mm and ranged from 58 to 121 mm. Hatchery fish that met the size criterion for implantation of the 90-d radio tag represented the upper 1.3% of the population. Hatchery fish that met the size criterion for implantation of the 9-d tag represented the upper 8.9% of the population. Hatchery fish that met the size criterion for PIT tagging represented the full distribution of the population.

Both CTWSRO and USFWS produced population abundance estimates for the Warm Springs River (Table 2). The estimates produced by USFWS using the Stratified Population Analysis System (SPAS) are more conservative than those by CTWSRO. USFWS did not use a correction factor to account for the amount of time the trap was operated. As a result, they could not use marking periods where recapture numbers were zero. The correction factor is based on the proportion of time that the trap was not in the water (high debris, trap frozen, and weekends). The population variation for wild Chinook salmon was low (11%) (Table 2). The population variation for hatchery Chinook salmon was high (27%). The difference in population estimates can be attributed to the method of estimating populations.

Table 2— Population estimates for wild and hatchery Chinook salmon, fall 2002. Data reported by CRFPO.

	CTWSRO Estimate	USFWS Estimate	Population Variation
Wild Chinook	45,234	23,198+/-2,663	11%
Hatchery Chinook	36,412	26,019+/-7,027	27%



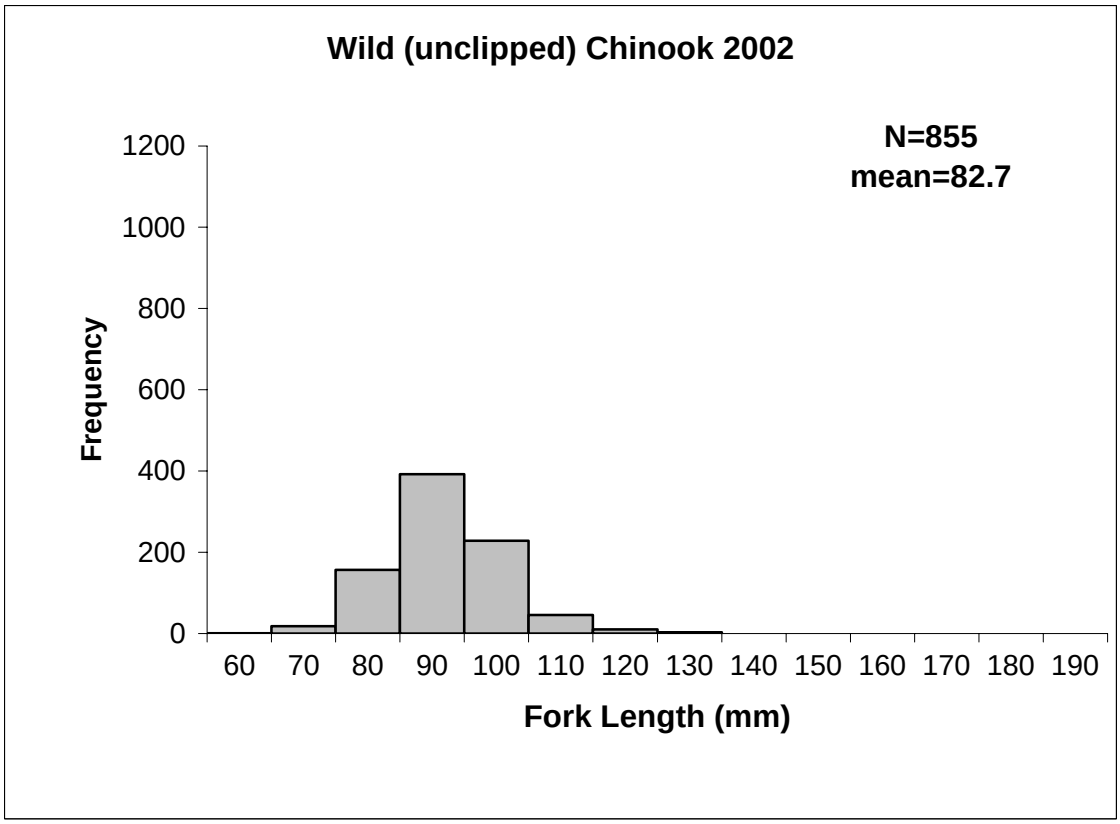


Figure 4—Size distribution of hatchery and wild juvenile Chinook salmon captured at the downstream migrant trap between 11 October and 17 December 2002.

Radio Tagging

During fall 2002 (1 November- 6 December), we radio tagged 25 juvenile Chinook salmon: nine with a 90-d tag and 16 with a 9-d tag (Table 3; Appendix 1). One fish was in poor condition 24 h after the tagging event and was removed from the study.

Although we had planned to implant 100 fish with the 90-d tag, the low number of fish collected at the trap that met the criteria prevented us from achieving this goal. Fish that met the size criteria (tag weight to body weight ratio of 5% or less) for implantation of the 90-d transmitters represented the upper 1.3% of the overall hatchery juvenile Chinook salmon distribution. When fish size at the trap was determined to not be sufficient, the smaller 9-d tag was added and used in the study. Sixteen fish were implanted with the 9-d tag. Fish that met the size criteria for implantation of the 9-d tag represented the upper 8.9% of the distribution.

Table 3—Tagging and release summary of radio-tagged juvenile Chinook salmon in the Warm Springs River, Oregon, 2002. Radio-tagged fish were surgically implanted with 9-d or medium (med) or large (Lg) transmitters.

Release number	Tagging date	Tag size	Num tagged	Number released	Fork length (mm)		Weight (g)	
					Mean	Range	Mean	Range
1	11/01/02	9-d	1	1	134	-	27.9	-
		90-d med	1	1	150	-	38.6	-
		90-d Lg	1	1	170	-	60.1	-
2	11/08/02	9-d	4	4	132	130-134	27.1	25.8-28.6
		90-d med	1	0	148	-	34.9	-
		90-d Lg	2	2	169	165-173	51.9	49.0-54.8
3	11/09/02	9-d	5	5	130	126-138	24.8	23.0-29.7
		90-d med	2	2	153	150-155	39.9	37.7-42.1
		90-d Lg	1	1	168	-	46.7	-
4	11/11/02	9-d	5	5	129	125-133	24.6	23.0-28.0
		90-d med	0	0	-	-	-	-
		90-d Lg	0	0	-	-	-	-
5	11/20/02	9-d	0	0	-	-	-	-
		90-d med	0	0	-	-	-	-
		90-d Lg	1	1	160	-	48.8	-
6	12/06/02	9-d	1	1	124	-	20.3	-
		90-d med	0	0	-	-	-	-
		90-d Lg	0	0	-	-	-	-

Migration Behavior and Mobile Tracking

Based on data obtained from fish implanted with the 90-d tags, we found that 37.5% (3 of 8) of the radio-tagged fish left the Deschutes River and 62.5% (5 of 8) remained in the Deschutes River (Table 4). All fish were documented leaving the Warm Springs River and entering the Deschutes River. The fixed site station located at Oak Springs did not perform as well and it did not detect all fish that passed by. Because no fish were contacted at the telemetry site upstream of the confluence of the Warm Springs River, all fish presumably moved downstream immediately after entering the Deschutes River. Fish that left the Deschutes River moved quickly and exited the 135-km study area in a median travel rate of 0.49 km/h and total travel time of 66.1 h (2.75 d) (Table 5). The travel rates of fish that exited ranged from 0.28 to 0.79 km/h, with total time to exit ranging from 37.2 to 106.3 h. Once fish left the Deschutes River, they were not detected in the Columbia River at either the Lyle site or the I-205 bridge. We used a combination of fixed site detections and mobile tracking detections to determine last contacts on our fish (Figure 5). At the end of the study, we determined that 5 fish remained in the Deschutes and were distributed downstream of the Oak Springs Hatchery. Fish that left the Deschutes River system were of similar size (157 mm) to fish that remained in the Deschutes (164 mm) and size ranges overlapped in both groups.

The 9-d tags were used as a supplement to the 90-d transmitters, allowing us to gain some information on smaller fish. Migration behavior was monitored for an 8 d period. Of the 16 fish that were implanted with the 9-d tag, 14 fish were documented leaving the Warm Springs River and entering the Deschutes River. Two fish were never contacted after release. No fish were contacted at the telemetry site upstream of the confluence of the Warm Springs River. Of the 14 fish that entered the Deschutes River, only one (7.1%) fish left the Deschutes system, leaving in 0.60 km/h. This fish was not detected at fixed arrays at Lyle or I-205 bridge. Seven fish were found distributed throughout the lower Deschutes, with six of these remaining upstream of Oak Springs. Six fish were never contacted after the initial detection at the Warm Springs fixed site station, however, the limited tag life did not allow much time for contacts.

From 15 November 2002 through 20 January 2003, CTWSRO and USGS personnel radio-tracked juvenile Chinook salmon in the Deschutes River. Mobile

tracking was conducted by vehicle about four days a week, allowing ground-truthing of fixed site data and determining where fish were holding. After the first two weeks, fish were found to hold in the same general area. The GPS could not be used in some areas due to interference caused by the steep canyon. Of the eight 90-d radio-tagged fish that were released, five remained in the Deschutes River for the length of the study. We were able to get multiple contacts using mobile tracking on these fish and determine holding locations (Figure 6). All fish tagged with 90-d transmitters that remained in the Deschutes held in the lower portion of the study area, below Oak Springs. Once a fish stopped migrating downstream, it remained in that general location, with some small-scale downstream migration, throughout the length of the study. We found that the 90-d radio-tagged fish spent most of their time in the lower section of the Deschutes River, below Oak Springs (Figure 7). When looking at the number of detections in our study area, we found that the most contacts were between Rkm 45 and 75 (Figure 7).

Table 4—Fixed site and mobile contacts summary of radio-tagged juvenile Chinook salmon in the Deschutes River, Oregon, 2002. Summary includes tag type, number of fish surgically tagged and released, number of fish that were contacted at fixed site stations (entering and exiting the Deschutes), and number contacted during mobile tracking.

Tag type	Tagged	Released	Entered Deschutes R.	Exited Deschutes R.	Contacted in Deschutes R.
2.0 g (90 d)	5	5	5	1	4
1.7 g (90 d)	4	3	3	2	1
0.85 g (9 d)	16	16	14	1	7
Total	25	24	22	4	12

Table 5—Travel times and rates of radio-tagged juvenile Chinook salmon that exited the Deschutes River, Oregon, 2002.

Tag Type	Travel time		Travel rate	
	Mean	Range	Mean	Range
90 d	66.1 h (2.75 d)	37.2-106.3 h (1.55-4.43 d)	0.49 km/h	0.28-0.79 km/h
9 d	81.6 h (3.4 d)	-	0.60 km/h	-

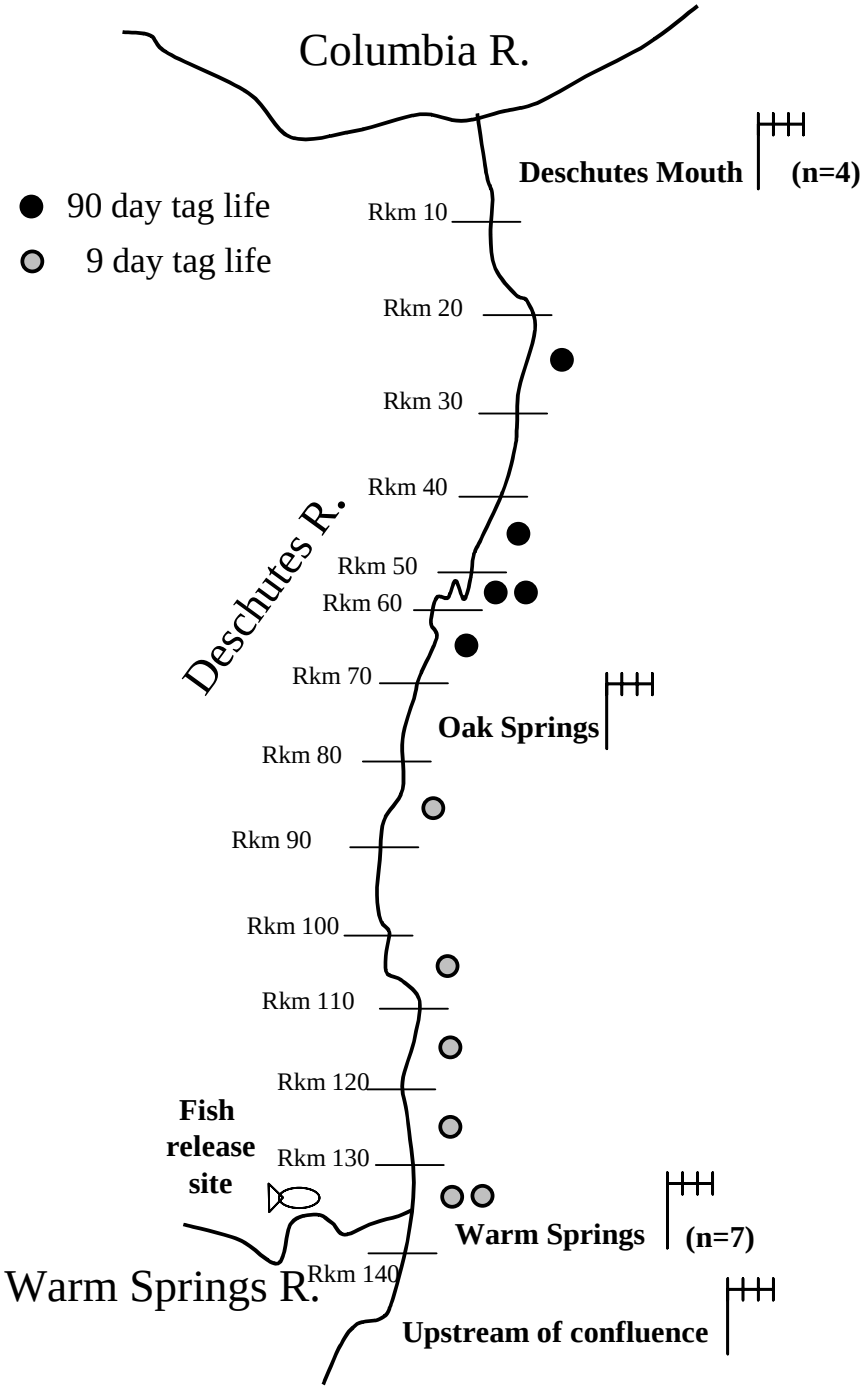


Figure 5—Last mobile detections (● ○) in 10 km reaches and number of fish with last contacts at fixed site stations (⊢⊣) of radio-tagged juvenile Chinook salmon in the Deschutes River, Oregon, 2002.

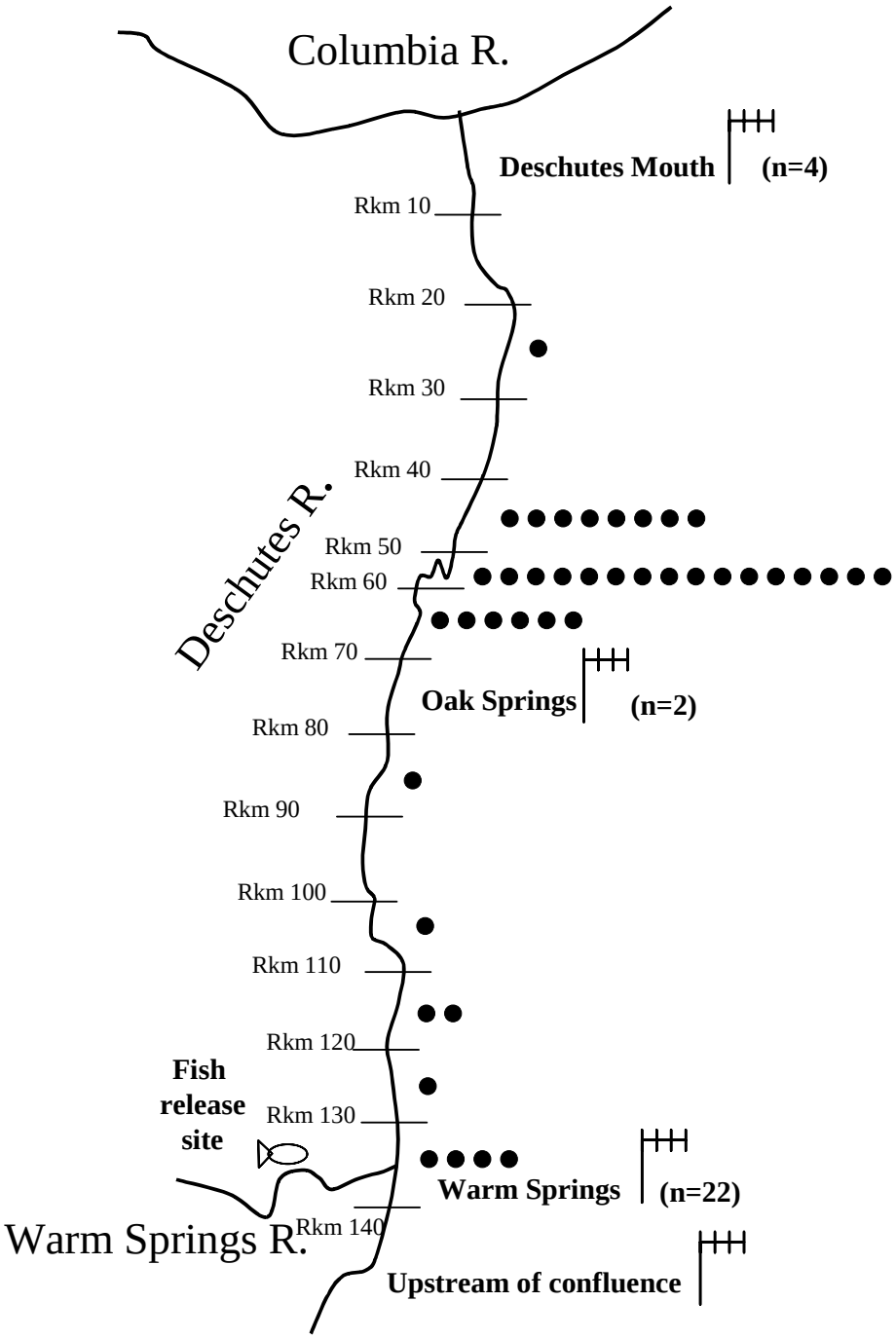


Figure 6—Mobile detections (●) in 10 km reaches and number of contacts at fixed site stations (⊢) of radio-tagged juvenile Chinook salmon in the Deschutes River, Oregon. Detections represent individual contacts of all types of radio tags, therefore showing multiple hits in cases where fish were contacted multiple times in the same reach.

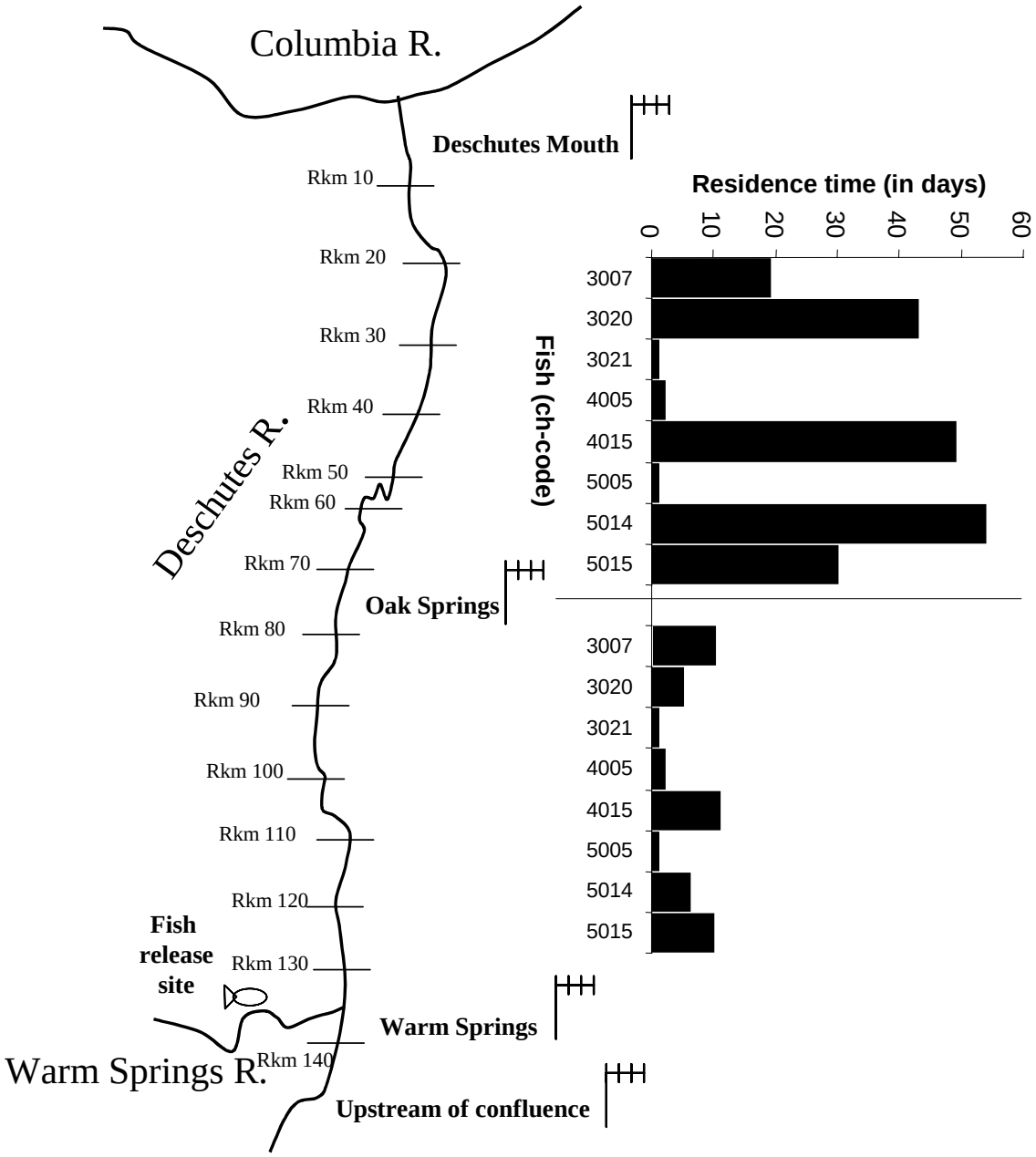


Figure 7—Residence times (in days) of juvenile Chinook salmon radio tagged with 90-d tags upstream and downstream of Oak Spring fixed site in the Deschutes River, 2002. Residence times were calculated using either fixed or mobile contacts.

ATPase

Mean ATPase activity of fish sampled at Warm Springs National Fish Hatchery was 5.5 μmoles ATP hydrolyzed/mg protein per hour (Table 6). Lengths of fish ranged from 70 mm to 183 mm, with a mean of 103.9 mm. Mean weight was 13.7 g and the mean condition factor (Fulton's K) was 1.199. The ATPase, condition factor, fork length, and weight were not different between ponds ($P>0.05$), therefore ATPase data was pooled. ATPase levels were not related to size at the hatchery ($R^2 = 0.0006$), (Figure 8). ATPase samples were not taken in 2002 at the migrant trap, due to a lack of available fish.

Table 6— Na^+, K^+-stimulated ATPase activity (μmol P_i·mg protein^{-1}·h^{-1}), condition factor (Fulton's K), fork length, and weight of juvenile Chinook salmon sampled at the Warm Springs National Fish Hatchery on 2 October 2002.

Pond	N	ATPase		Condition Factor		Fork Length (mm)		Weight (g)	
		Mean	STD	Mean	STD	Mean	STD	Mean	STD
5	25	4.9	1.8	1.175	0.200	107.0	18.2	14.0	3.6
6	24	6.0	1.5	1.203	0.074	99.9	8.9	12.3	3.6
7	26	5.6	2.0	1.232	0.062	102.9	6.3	13.6	2.7
8	24	5.1	1.8	1.208	0.049	103.8	6.3	13.6	2.5
9	25	6.0	2.0	1.221	0.091	108.3	12.4	16.0	6.0
10	21	5.3	2.1	1.190	0.055	100.5	7.5	12.3	3.0
25	29	5.9	1.6	1.167	0.051	105.0	7.8	13.8	3.3
26	28	4.9	1.8	1.194	0.050	104.4	9.2	13.9	4.1
27	29	5.6	1.8	1.197	0.062	103.3	6.6	13.4	2.8
Overall	231	5.5	1.8	1.199	0.077	103.9	9.3	13.7	3.5

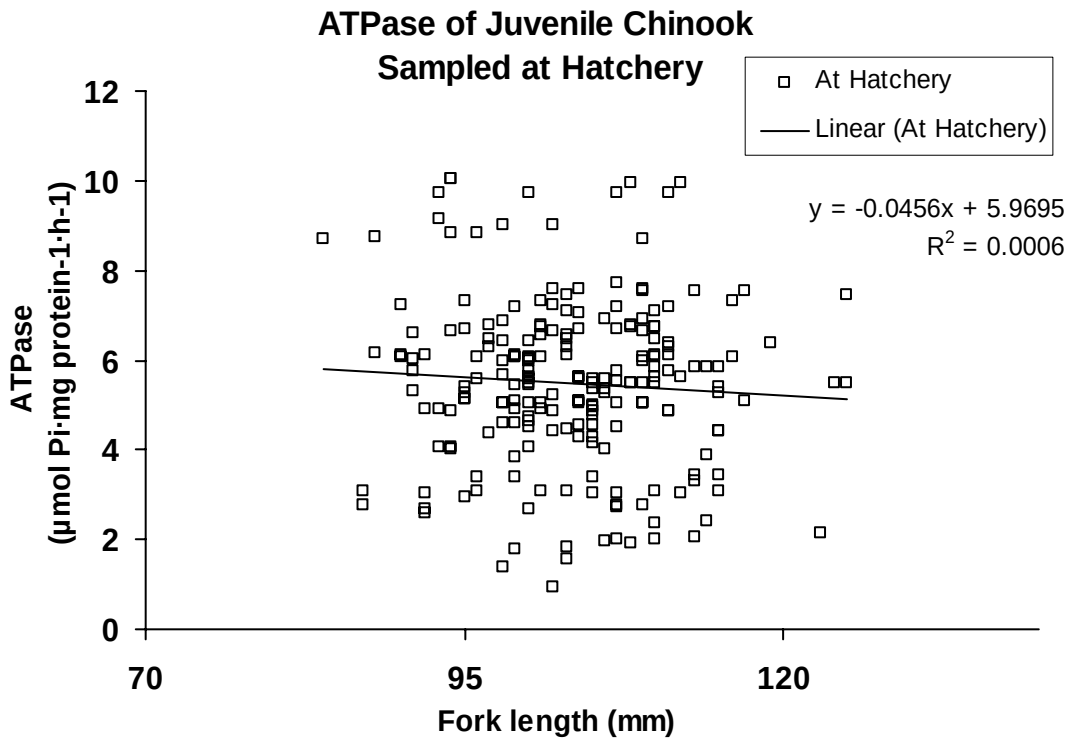


Figure 8—ATPase of juvenile Chinook salmon collected at the Warm Springs NFH on 2 October 2002.

PIT tagging

Because of low catch of fish at the trap, especially in the later part of the season, we were able to insert only 723 of the 1,000 PIT tags planned. Trap efficiency was likely compromised due to high debris loads, low flows, and freezing temperatures. Juvenile Chinook salmon that volitionally left the hatchery and subsequently were caught in our fish trap had a substantially different size distribution than what we expected (see section on size distribution above). Because the size distribution differed, we did not meet the planned stratification of tags across size classes (Table 7). This was especially true for the largest size class (>134 mm). Most of the fish that were caught in this size group were reserved for radio tagging. As a result, only five fish >134 mm were available for PIT tagging.

Table 7.—Number of juvenile spring Chinook that were PIT-tagged from 22 October – 21 November 2002. The number of fish tagged was distributed among three size classes. Those that were "double tagged" received a PIT tag and a radio tag.

Size class	Planned PIT tagging	Number PIT tagged	Number double tagged[1]
< 115 mm	375 (37.5%)	481 (66.5%)	0
115 – 134 mm	375 (37.5%)	238 (32.9%)	3 (75%)
> 134 mm	250 (25.0%)	4 (0.5%)	1 (25%)
Total	1,000	723	

[1] "Double tagged" refers to a fish that received a radio tag and a 12-mm PIT tag.

Detecting PIT tags in the Deschutes River

No PIT-tagged fish were detected during our sampling attempts. Our ability to detect fish was hampered by not having as many radio-tagged fish in the system as planned (100 planned versus 24 deployed). Most radio tags deployed were the 9-d tag (16 of 24) that had very limited life spans. Without the location of radio-tagged fish, searching for PIT-tagged fish alone was not deemed feasible. Though at least one radio-tagged fish was located before each of our raft trips, we originally envisioned that many radio tags would be in the system and that we would be conducting multiple visits to their many locations to locate PIT-tagged fish. With lack of radio-tagged fish in the system, the chance for detecting PIT-tagged fish was very low.

A large (152 cm by 30.5 cm) antenna was constructed and tested at Abernathy Fish Technology Center. The antenna was tested with three different reader configurations: 1) a 24 V DC backpack unit powered by internal batteries, 2) a 24 V DC unit powered with external batteries, and 3) a 24V DC unit powered with an AC/DC converter. The antenna was optimized to work with the mobile unit constructed for the project. The unit was tested in a raceway at AFTC. Noise levels were low and read range for the 12-mm PIT tags was about 15 cm.

A second, smaller (45.7 cm round) antenna was constructed with a 0.4-m extension pole. The antenna was tested at AFTC. Noise levels were low and read range with the 12-mm tag was about 30.5 – 40.6 cm off the plane of the antenna (exceeding previously determined acceptable ranges).

Three raft trips were conducted in the Deschutes River to attempt to find PIT-tagged fish downstream from the mouth of the Warm Springs River. One to three days before the raft trips, mobile radio tracking efforts were conducted to locate radio/PIT tagged fish. These radio/PIT tagged fish could be precisely located with the radio telemetry equipment on board the raft. Once located, the portable PIT tag reader was used to attempt to locate the same fish.

The first rafting trip on the Deschutes River was conducted on 21 November 2002. The first 4.8 km downstream from the mouth of Warm Springs River was sampled using the PIT tag reader. Three days prior to the trip, two double-tagged fish were located by radio tracking efforts. These fish could not be relocated by radio telemetry

gear on board the raft. It is possible that these fish moved elsewhere or that the 9-d-tag batteries had expired. An effort was made to deploy the mobile PIT-tag detector in areas where juvenile Chinook salmon were likely to hold. No PIT tags were detected.

A second rafting trip was conducted on 5 December 2002. A double-tagged fish (90-d tag) was located prior to and during the raft trip between Sherars Falls and Max Canyon. Using the radio telemetry gear, we found that the double-tagged fish was holding in a seam between the main flow and a large eddy. Several juvenile Chinook salmon were visually observed to be holding in this habitat. The PIT-tag detector unit was tuned at the boat ramp, and the crew attempted to find the double-tagged fish using the PIT tag reader. Although the fish was accurately located using radio telemetry gear, we did not detect the fish after multiple passes with the PIT detector unit. A third rafting trip was conducted the following week to attempt to find this same fish. The fish was again located using the radio telemetry equipment. An attempt to detect the PIT tag in this double-tagged fish was again unsuccessful in spite of being able to get very near the fish.

Discussion

Radio Telemetry, Migration Behavior

Based on the 90-d radio transmitters, we found variable migration behaviors in radio-tagged juvenile Chinook salmon once they left the Warm Springs River. Of the eight radio-tagged fish released, 37.5% (3) migrated through the Deschutes River and entered the Columbia River. The remaining 62.5% (5 fish) distributed in the lower Deschutes River until the end of the study period in February. Although the sample size was small, this migration data is consistent with our 2000 pilot study that found 35% of the radio-tagged fish exited the Deschutes River and 65% remained. Fish that left the Deschutes River moved through the 135 km stretch of river quickly, exiting in a median travel time of 66.1 h (2.75 d). This was similar to what was found in 2000 where median travel to exit was 38.4 h (1.60 d). With such a small sample size, we did not find that size was a factor in migration behavior of the 90-d tagged fish as we had in 2000.

The addition of the 9-d tags to our study allowed us to radio-tag and monitor smaller fish. This provided insight for a short window of time (8 d) into migration behavior of smaller fish and potential size-dependent differences in migration behavior. Based on the 9-d tags, we found a smaller number of radio-tagged fish leaving the Deschutes River. One of fourteen fish (7%) left the Deschutes River during the first eight days after release. Use of the 9-d tags reinforced our 2000 findings that found size may be a factor in migration behavior. Smaller fish were more likely to remain in the Deschutes system. Size-dependent migration behavior is consistent with the findings of Beckman et al. (1998), who found that larger hatchery fish had a greater disposition to migrate. Of the 14 fish that entered the Deschutes River, only one continued to migrate and exit the Deschutes River. The remaining fish were in the river or were not contacted again. Based on 2000 data, we found that if fish were going to exit the river, migration typically occurred within the first week after release.

Although our sample size was small, we were able to characterize the migration behavior of fall-released fish. However, due to size constraints related to tag and body-weight ratios, we tagged only the largest fish in the fall release. Due to size-selective tagging, our results from the 90-d tags conservatively apply to the upper 1.3% of the hatchery fish size distribution and from 9-d tags apply to 8.9% of the size distribution. If

smaller fish tend to stay in the Deschutes River, and large fish exit the system, we may have underestimated the number of fish that stay in the river. Had we tagged a representative group of fish from the remaining 90.1% of the population, the percentage of fish staying in the system would likely have been much higher than 62.5%.

The migration behavior of the fish after they leave the Deschutes River remains unknown. None of the fish that exited the Deschutes River were contacted at downstream fixed telemetry arrays. Other telemetry studies at the USGS with similar tags were found to have high detection probabilities (over 90%) at both of our fixed sites at Lyle and I-205 (Counihan et al 2003). However, there were some differences in tag type, as well as water conditions (temperature, conductivity, etc.).

ATPase

Variation in ATPase levels of fish taken at the hatchery was not explained by fish size in 2002 (R^2 =0.0006) and the results are consistent with findings from 2000 (R^2 =0.0246). ATPase results from 2000 and 2002 showed no indications toward the parr-smolt transformation in relation to size. Results reported in Zaugg (1985) and from observations of many other hatchery populations suggested that most anandromous salmonids in the Columbia River system do not develop maximum hypo-osmoregluatory capability while confined to the hatchery environment, but appear to require a period of active downstream migration. We do not know the ATPase levels of fish as they left the hatchery, so it is hard to determine if elevated ATPase caused fish to leave the hatchery, or if once leaving the hatchery, their ATPase levels changed while in river. Beckman (1998) showed that there was a strong relation between fish size and growth rate and advanced state of smoltification. This may result in a greater propensity of larger fish to move downstream when released into a natural system.

Since we did not sample at the trap in 2002, we do not know the ATPase activity of fish that migrated out of the hatchery, or if there was a positive correlation between size and ATPase activity, as seen in 2000. A positive relation between fish size and ATPase may help to explain the greater disposition of larger fish to migrate. Several studies have shown that physiological smolt development and development of downstream migratory tendencies are correlated (Beckman et al. 1998). Hart et al.

(1981) found hatchery Chinook salmon with higher ATPase activities migrated out of rearing channels sooner than fish with lower ATPase activities. Beckman (1998) suggested that physiological change and migration behavior are temporally linked.

PIT-tagging

The third objective of the study was to determine the feasibility of using PIT-tag technology to determine distribution of juvenile spring Chinook after their volitional release in fall from the Warm Springs NFH. While PIT-tag technology has become widespread in recent fisheries investigation (Achord et al. 2001; Zydlewski et al. 2001; Jezorek et al. 2003), our attempt to use mobile devices to detect PIT-tagged fish in a large and fast-flowing river represented a unique application requiring much innovation. The evaluation of this new detection method was cooperatively conducted by personnel from USFWS, CTWSRO, and USGS.

Use of PIT tags offer enhanced ability to monitor the fate of individual fish for studies of habitat use, population structure, survival, and responses to environmental variables (Lucas 2000; Bell et al. 2001; Muir et al. 2001). Because of their small size (12 mm in length), PIT tags can be inserted in much smaller fish than radio tags (typically 120 mm or longer). Because of their long life span, PIT tags can potentially enable tracking individual fish for many years versus the few days to months that the currently available radio tags last for small fish. PIT tags are also relatively inexpensive (under $3 per tag). About 80 PIT tags can be deployed for the price of a single radio tag. Despite all these advantages, a major disadvantage is that current technology requires that a detecting antenna must sweep very close (under 15-25 cm) to determine if a fish has a PIT tag. Short of actually capturing the fish for a second time, passively detecting a PIT-tagged fish in fast-flowing water with a mobile unit presents many challenges.

From our PIT-tag detection efforts, it was determined that modifications still need to be made to the PIT-tag detector unit. Among these are: having the manufacturer troubleshoot why the unit loses power quickly, more solid state construction of the reader in order to withstand tuning in the rain, and possibly new antenna construction. Other options for maximizing tag read range include using the new 12-mm super PIT tags or 23-mm PIT tags. Either of these tags will enhance the range of detection of the unit.

Our PIT-tag detection efforts were met with little success in terms of fish detection data, but our efforts were met with much success in terms of testing feasibility and advancing future design concepts. We remain convinced that the development of PIT-tag technology for use in extreme conditions like large white-water rivers is a worthy pursuit and promises to substantially increase our understanding of how juvenile salmonids use these systems.

Study Constraints

The lack of test fish affected most components of our study (radio telemetry, ATPase sampling, PIT-tagging). The smaller fish in 2002 compared to previous years may be attributed to a number of causes. Hatchery fish produced at the Warm Springs NFH were smaller in 2002 than in previous years. This was due to a change in feeding regime as well as a die-off in the spring that killed many of the larger fish at the hatchery (USFWS, personal communication with Mike Paiya). Weather patterns in 2002 were not typical of fall weather conditions at Warm Springs. In most years there is a decrease in temperature that coincides with an increase in precipitation. Increasing flow causes fish to migrate out of the hatchery and Warm Springs River. In fall 2002, there was not much precipitation or significant increase in flow.

We found that fish captured at the migrant rotary screw trap in 2002 were not as large as those captured in previous years. Comparing 2002 screw trap data to the migrant Humphrey trap data in 2000, we found that the mean size of juvenile spring Chinook salmon (both hatchery and wild) was smaller in 2002. The mean size of hatchery spring Chinook salmon in 2002 was 109 mm compared to 122 mm in 2000. Comparatively, the size of wild spring Chinook salmon caught at the trap was also smaller. The mean size of wild spring Chinook salmon in 2002 was 83 mm compared to 96 mm in 2000. This information suggests that the trap was more size selective than prior years.

Concerns regarding the location and rate of rotation of the migrant trap were identified when it was found that the trap was rotating at less than one rotation per minute. Rate of rotation is directly related to flow and efficiency of capture. Since flows were low in 2002, this decreased the rate of rotation, at times, to less than one rotation per minute. In a study by Roper (1996), trap efficiencies for hatchery fish ranged from 1 to

26%, and these fish were captured at significantly lower rates when the trap was positioned in areas of lower-velocity water. Trap efficiencies were similar for wild and hatchery fish when the trap was in high-velocity water but differed significantly when the trap was in slow water. The trap efficiencies and population estimates reported by CTWSRO and USFWS were different. Findings by Roper (1996) suggest that trap efficiencies should be estimated independently for wild and hatchery fish until it is empirically demonstrated that the respective efficiencies are similar. Trap efficiencies vary between species and among fish sizes within a species. When the trap was rotating slowly, fish (especially larger fish) were able to swim out of the trap. This indicates that there may be a bias toward the capture of smaller fish and this may have contributed to the inability to capture larger fish for our study. Further investigation into the optimal rate of rotation, as well as trap location, is recommended.

Conclusions

Based on our findings using the 90-d tag we found that 62.5% of fish tagged remained in the Deschutes River and that the fall release was estimated to be 30,000 to 75,000 fish. We estimate that 18,900-47,250 hatchery fish distributed throughout the lower Deschutes River in fall 2002. Based on our findings from the 9-d tag, which represent the smaller fish, our estimates would probably be much higher. Additional studies are needed to further examine annual variability, migration, fish distribution, and potential interactions that may occur in the Deschutes River.

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Appendix A. Summary of individual radio-tagged fish in 2002. Summary includes transmitter frequency, fish length, weight, condition factor (K), size of tag implanted, release date, last contact information, and tag-body weight ratio. Last contact information is shown as either the last time contacted at a fixed site station (Exit, Warm Springs, Oak Springs) or kilometer where the fish was last detected while mobile tracking.

Frequency	Fork Length (mm)	Weight (g)	K factor	Tag Size	Release Date	Last Contact		Tag-Body weight ratio (%)
						Location	Date	
03-020	160	48.8	1.19	Large	11/21/02	57 km	11/26/2002	4.10
03-021	170	60.1	1.22	Large	11/2/02	EXIT	11/4/2002	3.33
05-014	165	49	1.09	Large	11/9/02	38 km	11/27/2002	4.08
05-015	168	46.7	0.98	Large	11/10/02	64 km	11/20/2002	4.28
04-015	173	54.8	1.06	Large	11/9/02	51 km	11/27/2002	3.65
03-007	155	42.1	1.13	Medium	11/10/02	62 km	11/20/2002	4.04
04-005	148	34.9	1.08	Medium	Not Released	-	-	4.87
04-005	150	37.7	1.12	Medium	11/10/02	EXIT	11/14/2002	4.51
05-005	150	38.6	1.14	Medium	11/2/02	EXIT	11/4/2002	4.40
03-064	126	23	1.15	Nano	11/10/02	Warm Springs	11/11/2002	3.70
03-065	125	23	1.18	Nano	11/12/02	101 km	11/19/2002	3.70
03-066	130	27.5	1.25	Nano	11/9/02	121 km	11/15/2002	3.09
04-015	134	27.9	1.16	Nano	11/2/02	Warm Springs	11/2/2002	3.05
04-016	133	28	1.19	Nano	11/12/02	No contacts	11/12/2002	3.04
04-017	138	29.7	1.13	Nano	11/10/02	Warm Springs	11/10/2002	2.86
04-018	128	23.2	1.11	Nano	11/10/02	133 km	11/18/2002	3.66
05-062	129	23.7	1.10	Nano	11/12/02	84 km	11/19/2002	3.59
05-063	130	25	1.14	Nano	11/10/02	Warm Springs	11/10/2002	3.40
05-065	130	26.6	1.21	Nano	11/9/02	Warm Springs	11/10/2002	3.20
05-070	128	23.8	1.13	Nano	11/12/02	117 km	11/15/2002	3.57
06-014	134	28.6	1.19	Nano	11/9/02	133 km	11/15/2002	2.97
06-016	126	23	1.15	Nano	11/10/02	Warm Springs	11/10/2002	3.70
06-101	132	25.8	1.12	Nano	11/9/02	No contacts	11/9/2002	3.29
06-118	130	24.7	1.12	Nano	11/12/02	68 km	11/20/2002	3.44
06-073	124	20.3	1.06	Nano	12/7/02	EXIT	12/11/2002	4.19

Chapter 2

Studies of behavioral interactions between juvenile salmonids in artificial streams: a literature review

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Introduction

To learn more about possible behavioral interactions between fish in the Deschutes River, the USFWS and the Warm Springs NFH are considering building some artificial streams to study such interactions in more detail. However, before embarking on a potentially costly endeavor with unknown efficacy, we were asked to review the relevant literature on behavioral interactions between various species of salmonids, with an emphasis on the influence of hatchery spring Chinook salmon on other fish. This review will describe the types of interaction studies that have been done and the various experimental systems that have been used to conduct such studies. Included is a discussion of the advantages, disadvantages, and design considerations of the various experimental systems (e.g., aquaria, mesocosms, in-stream enclosures) used to conduct such studies. The goal of this review is to help plan and guide future species interactions studies that may occur within the scope of the Warm Springs-Deschutes River research plan.

Literature review

The studies we reviewed covered a wide range of species and experimental designs (Table 1). The scope of our review covered major journals in fisheries and the behavioral sciences and spanned from the 1950's to the present. Only studies that actually conducted behavioral interaction experiments in artificial or semi-artificial systems using juvenile salmonids as test animals were included in the review. In total, we reviewed over 100 manuscripts. Of these, 43 met the criteria for inclusion into this review.

Types of experiments

We categorized the behavioral interaction studies into one of three general types: (1) multi-species; (2) single species; or (3) hatchery-reared vs. wild fish. The studies were fairly evenly divided amongst the three categories: 15 involved multi-species, 16 used only a single species, and 13 had a clear hatchery-reared vs. wild fish aspect to them. All studies assessing interactions between hatchery-reared and wild fish involved

only a single species. In total, 11 speices of salmonids were represented in these studies. The most commonly studied species were steelhead and rainbow trout, coho salmon (*O. kisutch*), and Chinook salmon, each appearing in 9 or more studies. Atlantic salmon (*Salmo salar*), brook trout (*S. fontinalis*), and cutthroat trout (*O. clarki*) were the test subjects in 5-7 studies, whereas brown trout (*S. trutta*), Arctic charr (*S. alpinus*), lake trout (*S. namaycush*), and Dolly Varden (*S. malma*) appeared in only 1 or 2 studies each.

Studies involving multi-species interactions had several dominant themes. In general, the studies compared some behavioral aspects between two species or assessed the effects of one species on various measures of performance in another species. Most studies focused on the rate and intensity of agonistic interactions between species (e.g., Newman 1956; Noakes 1980; Glova and Field-Dodson 1995), but other topics included the influence of one species on the growth or feeding of another (e.g., Fraser 1969; McMichael et al. 1997; McMichael and Pearsons 1998), habitat use and partitioning between species (e.g., Griffith 1972; Taylor 1991), territoriality (Symons 1974), and the influence of behaviorial interactions on predation or physiological stress responses (e.g., Pearsons and Fritts 1999; Kelsey et al. 2002). Most studies used groups of fish, either in sympatry or allopatry, to assess interactions between species. Studies using pairs of fish, one from each species, were relatively rare. Observations of interactions between fish were most often done in real time by human observers. Videotape was used in one study (Kelsey et al. 2002).

All studies using only a single species assessed, in some way, intraspecific aggressive interactions. Although it may not have been the dominant theme in all studies, the rate and type (e.g., nips, chases, or displays) of aggression elicited by groups or pairs of fish was always addressed. Some studies were new descriptions of the behaviorial repertoire of certain species (e.g., Hoar 1954; Stringer and Hoar 1955), but most addressed the influence of agonsitic interactions on some other variable, or vice versa. Some topics were similar to those of multi-species studies, including territoriaity (Dill 1974; McNicol and Noakes 1981, 1984), feeding (Slaney and Northcote 1974; Ryer and Olla 1995), and growth (Yamagishi 1962; Mikheev et al. 1994). Other studies addressed more novel topics such as the role of genetics in agonistic behavior (Rosenau and McPhail 1987; Taylor 1990), the energetic costs of behavioral interactions (Li and

Brocksen), social behavior as a cause of emigration (Chapman 1962; Jenkins 1971), and the influence of enriched versus conventional hatchery rearing environments on social behavior (Berejikian et al. 2000, 2001). Most studies used groups of fish, often using size as a variable, but some assessed dyadic interactions. Observations were most commonly done by humans.

Studies addressing interactions between hatchery-reared and wild fish were generally comparative in nature, focused on differences in aggressive behavior, feeding, growth, or survival between fish of different ancestry. Common themes underlying this body of research were trying to understand the potential negative impacts of stocking hatchery fish in waters with wild fish and the reasons for the apparent poor survival of hatchery fish after stocking. Hatchery-reared fish were often found to more aggressive than their wild counterparts (Fenderson et al. 1968; Mesa 1991; Swain and Riddell 1990; Berejikian et al. 1999) and an excessive use of energy was commonly cited as a reason for the poor survival of hatchery fish after stocking (e.g., Miller 1958; Mesa 1991; Deverill et al. 1999). However, many factors, such as size, density, and prior residence, can influence the outcome of aggressive interactions (Fenderson and Carpenter 1971; Berejikian et al. 1996; Deverill et al. 1999). Most studies were done using groups or pairs of fish; one study used single fish in mirror image stimulation tests (Swain and Riddell 1990). Studies were about evenly split in their use of fry or juveniles and adults.

Experimental systems used

We categorized the systems used in these studies into four general groups: (1) aquaria; (2) simple tanks or troughs; (3) more complex artificial streams; and (4) in-stream enclosures. The majority of studies (48%) used some type of artificial stream, followed by studies that used tanks or troughs (25%), aquaria (20%), and stream enclosures (7%). Some attributes of the four types of experimental systems are listed in Table 2. Because artificial streams were the most commonly used system and their construction for future species interaction work under the Warm Springs-Deschutes River research plan seems probable, the rest of this section will focus on the design and use of artificial stream environments.

Warren and Davis (1971) provide an excellent summary of the use of laboratory streams for research and the applicability of results to natural systems; I will highlight some of their main points here. Artificial streams have been used to study a variety ecological, behavioral, and physiological phenomena, including the production of stream plant communities, the feeding, territorial, and agonistic behavior of fishes, the reproductive behavior of aquatic animals, community trophic relations, and the effects of environmental change (e.g., pollution) on stream communities. Basically, there are two types of artificial streams: (1) closed, or partially-closed systems, where most of the water is recirculated and only a small water exchange takes place; and (2) open, or flow-through systems, where a single water mass passes through the entire system. Only the open systems have the singular natural stream characteristic of continual downstream movement of the entire water mass, exporting suspended and dissolved materials and preventing their accumulation in one place. Artificial streams have many advantages, including conceptual focus, spatial limitation, simplification, control, manipulation, and measurement. In fact, as alluded to in Table 2, other artificial systems, such as aquaria or tanks, have similar advantages. However, working with artificial systems means we lose a great deal of reality, which may place severe constraints on the relevance of any conclusions we might reach. When comparing the use of aquaria, tanks, and artificial streams for species interactions work, the highest degree of ecological realism would come from the use of properly designed, flow-through artificial streams. In such systems, we can provide riffle and pool environments, proper light levels, substrate types, temperatures, and water qualities, yet still have the much needed reality, control, and convenience of observation. Although, for truly autecological studies, it may not be necessary for artificial streams to closely mimic natural complexity, species interaction studies would likely benefit from an experimental environment that resembles the natural complexity of streams. This is because many factors, such as flows, substrates and cover, food availability, temperature, and fish density, can influence the extent and outcome of interactions between two species.

In the studies we reviewed, 16 of them used closed artificial streams and 10 used open or in-stream systems. I qualitatively categorized the ecological realism of these systems into three groups—low, moderate, or high—based on well they simulated these

natural stream characteristics: (1) size; (2) pool/riffle sequences; (3) use of substrates; (4) overhead cover; (5) underwater feeders simulating insect drift; (6) ambient photoperiod control; and (7) ambient temperature control. For the closed systems, 4 were judged as having high ecological realism (Griffith 1972; Glova 1986; Dolloff and Reeves 1990; Mesa 1991), 9 were moderate (e.g., Symons 1974; Swain and Holtby 1989; Berejikian et al. 1999), and one had low realism (Rosenau and McPhail 1986). In one study (Chapman and Bjorrn 1969), a lack of detailed description in the methods precluded a valid ranking of their artificial stream. For the artificial streams that had high ecological realisim, only one (Glova 1986) seemed to address all seven of the characteristics described above. This system was originally described by Hartman (1965) and measures 5 m long x 1.2 m wide x 0.7 m deep, has duplicate pool/riffle sequences with undercut areas, a mixture of fines, gravels, and small and large cobbles, in-stream woody debris, underwater feeders, and control over the water temperature and photoperiod. The artificial streams used by Dolloff and Reeves (1990) and Mesa (1991) were the same and are described in detail in Reeves et al. (1983). These were smaller, duplicate oval-shaped artificial streams that lacked only distinct overhead cover. The two artificial streams used by Griffith (1972) were designed to simulate the dimensions, water velocity, and substrate of pools in local streams. All of these streams had water velocities created by pumps or motors and paddle wheels, viewing windows of glass or plexiglass along the side of the stream channel, and were suitable for behavioral studies of groups of juvenile fish. The artificial streams used by Griffith (1972), Dolloff and Reeves (1990), and Mesa (1991) were in duplicate, thus providing some measure of replication of experimental treatments.

The artificial streams rated as having moderate ecological realism generally lacked 2 or more of the characteristics described above. Commonly, these were a lack of pool/riffle sequences, underwater feeders, overhead cover, or substrate. Some of these artificial streams were quite large (e.g., Symons 1974; Berejikian et al. 2000), others were relatively small (e.g., Swain and Holtby 1989; Taylor 1990), and all, in one way or another, seemed to lack the specific details of the systems described in the previous paragraph. Despite this, the results derived from these studies were apparently of high quality since many were published in well-known journals. The mechanics of moving water, maintaining temperature, and controlling photoperiod were similar to those

artificial streams with a higher degree of ecological realism. Also, the majority of artificial streams in this category (7 of 9 studies) had some capacity for simultaneous replication of treatments.

All of the open systems we reviewed had the natural stream characteristic of a single water mass flowing through them. Despite this, not all of these systems had a high degree of ecological realism. Most of the open systems with low to moderate ecological realism were flumes with a single-pass, natural water source (e.g., Stein et al. 1972; Slaney and Northcote 1974; Dickson and MacCrimmon 1982; Mikheev et al. 1994). However, like many of the closed systems, they were often lacking pools and riffles, natural or simulated natural foods, substrates, cover, or a range of flows. Those studies that had high ecological realism often, but not always, used a blocked off section of a natural stream or spawning channels. For example, Chapman (1962), Jenkins (1969, 1971), and McMichael and Pearsons (1998) blocked off large sections of a stream for their research. Consequently, the only unnatural aspect of these open systems was the actual screens used to delineate the experimental area. Detailed behavioral observations were made by snorkeling or from overhead towers. Fraser (1969) modified large experimental spawning channels with concrete blocks, substrates, and cover to produce 4 replicate artificial streams with pools and riffles, natural foods, and different velocities. Glova and Field-Dodgson (1995) and Deverill et al. (1999) built flow-through simulated streams with all of the natural stream characteristics discussed above. These systems had the added advantage of being able to observe behavior through banks of windows.

Summary and recommendations

Research on behavioral interactions of fishes has a long history and the use of artificial stream environments has been critical to the success of this body of work. In short, the use of artificial streams has been, and will continue to be, critical to the understanding of species interactions. Much of what has been learned from the study of fish in artificial streams, such as behavioral repertoires, territoriality, habitat preferences, and competition, has been corroborated in numerous field studies. Despite the plethora of research on behavioral interactions between salmonids in artificial streams, there is still more to learn. For example, detailed interactions between bull trout and other

species is currently lacking and would be relevant to the situation in the Deschutes River. Two other aspects would also be relevant to the situation in the Deschutes River, namely behavioral interactions between fish undergoing smoltification and the influence of prior residence on interactions between fishes.

For future species interaction work to be conducted under the Warm Springs-Deschutes River project, I recommend construction of duplicate flow-through artificial streams. Although specific design elements can be developed in the future, the streams should have the following characteristics: (1) water pumped or gravity fed from a local stream; (2) be long enough to have two pool and two riffle environments with different water velocities; (3) be wide enough to accommodate groups of two or more species at one time; (4) be filled with substrates of different sizes in a mixture similar to local streams; (5) have natural insect drift as the main food source, perhaps supplemented by underwater feeders; (6) be located outside or under skylights for exposure to natural photoperiod; (7) be elevated with windows on one or both sides for observing behavior; and (8) have some in-stream and overhead cover. In addition to these characteristics, it may be desirable to have some ability to control water temperature and some degree of sinuosity. New technology, such as PIT tags and flat plate readers, provide potential for design features that will add ease and precision to data collection. These artificial streams should of course closely mimic the characteristics of a natural stream and would have several advantages over closed systems or in-stream enclosures. Closed systems, because of their common design feature of recirculating water, are relatively small and present unique challenges for temperature control and natural feeding. As evidenced above, however, they can be designed to have a high degree of ecological realism and would be a valid choice if there were concerns about space or water supply. Although conducting species interaction work in natural streams has high ecological realism, there are numerous drawbacks when compared to properly designed flow-through systems. Working in natural streams: (1) usually offers less ability for replication of treatments; (2) renders behavioral observations more difficult and less precise since it involves either snorkeling or overhead viewing; (3) requires that stream reaches be “cleaned out” before new animals are stocked; (4) involves design and construction of upstream and downstream barriers; and (5) may be more prone to natural disasters, such as unexpected

freshets or storms, that could ruin an experimental set up. Perhaps an ideal way to study species interactions relevant to the Warm Springs-Deschutes River project is to conduct detailed research in artificial stream environments followed by direct observation, and even telemetry, of fishes in the natural stream. This would allow some confirmation of results obtained from the artificial systems and provide the best information available to managers for informed decision making.

Table1. List of studies reviewed covering a wide range of species and experimental designs.

Species	Study Theme	Study apparatus	Author	Year
Atlantic salmon	Territorial defense	Artificial stream	Symons, E. K.	1974
	Behavior differences by sizes	Artificial stream	Mikheev, V. N., et al.	1994
	Crowding, behavior	Aquaria	Fenderson, O. C. and M. R. Carpenter	1971
	Agonistic and feeding behavior	Aquaria	Fenderson, O. C., et al.	1968
	Growth and behavior	Stream tanks	Dickson, T. A. and H. R. MacCrimmon	1982
Brook charr	Territory defense	Lab stream channels	McNicol, R. E. and D. L. G. Noakes	1984
	Territory defense	Lab stream channels	McNicol, R. E. and D. L. G. Noakes	1981
Brook trout	Territoriality	Artificial stream	Symons, E. K.	1974
	Vertical distribution	Troughs	Moyle, P. B.	1969
	Interspecific competition	Aquaria	Newman, M. A.	1956
	Habitat, agonistic behavior	Lab stream channels	Griffith, J. S., Jr.	1972
Brown trout	Territory, aggression	Artificial stream	Deverill, J. I., et al.	1999

Table 1 (Continued). List of studies reviewed covering a wide range of species and experimental designs.

Species	Study Theme	Study apparatus	Author	Year
	Dominance, aggression	Simulated stream	Glova, G. J. and M. S. Field-Dodgson	1995
Charrs	Behavioral observations	Plexiglass tanks	Noakes, D. L. G.	1980
Chinook salmon	Food related diurnal distribution	Stream aquaria	Chapman, D. W. and T. C. Bjornn	1969
	Intraspecific agonistic behavior	Stream tanks	Taylor, E. B.	1990
	Dominance, aggression	Simulated stream	Glova, G. J. and M. S. Field-Dodgson	1995
	Behavior, physiology	Rectangular fiberglass tanks	Kelsey, D. A., et al.	2002
	Growth, abundance	Stream barriers	McMichael, G. A. and T. N. Pearsons	1998
	Behavior, habitat use	Lab stream channels	Taylor, E. B.	1991
Coho salmon	Dominance, growth	Lab stream channels	Berejikian, B. A., et al.	1999
	Agonistic behavior	Aquaria	Swain, D. P. and B. E. Riddell	1990
	Aggression	Large plexiglass arena	Dill, L. M.	1978
	Agonistic behavior	Aquaria	Rosenau, M. L. and J. D. McPhail	1987

Table 1 (Continued). List of studies reviewed covering a wide range of species and experimental designs.

Species	Study Theme	Study apparatus	Author	Year
	Aggressive behavior	Stream aquaria	Chapman, D. W.	1962
	Growth, survival	Experimental stream channels	Fraser, F. J.	1969
	Dominance, behavior	Troughs	Stein, R. A., et al.	1972
	Behavior, habitat use	Lab stream channels	Taylor, E. B.	1991
	Survival, growth	Raceway, fish barrier falls	Rhodes, J. S. and T. P. Quinn	1999
Cutthroat trout	Feeding behavior, interaction	Tanks	Schutz, D. C. and T. G. Northcote	1972
	Survival	Instream barriers	Miller, R. B.	1954
	Feeding, aggression	Artificial stream	Mesa, M.G.	1991
	Agonistic behavior	Tanks	Nilsson, N. A. and T. G. Northcote	1981
	Habitat, agonistic behavior	Lab stream channels	Griffith, J. S., Jr.	1972
Dolly Varden	Feeding behavior, interaction	Tanks	Schutz, D. C. and T. G. Northcote	1972
Fall Chinook salmon	Dominance, social behavior	Troughs	Stein, R. A., et al.	1972

Table 1 (Continued). List of studies reviewed covering a wide range of species and experimental designs.

Species	Study Theme	Study apparatus	Author	Year
Rainbow trout	Intraspecific competition	Lab stream channels	Li, H. W. and R. W. Brocksen	1977
	Territory size, aggression	Lab stream channels	Slaney, P. A. and T. G. Northcote	1974
	Aggression, territorial defense	Aquaria	Stringer, G. E. and W. S. Hoar	1955
	Behavior, aggression	Outdoor stream channel	Jenkins, T. M., Jr.	1971
	Aggression, age	Aquaria	Chiszar, D. and R. W. Drake	1975
	Growth, behavior	Aquaria	Yamagishi, H.	1962
	Interspecific competition	Aquaria	Newman, M. A.	1956
	Growth, abundance	Stream barriers	McMichael, G. A. and T. N. Pearsons	1998
	Agonistic behavior	Tanks	Nilsson, N. A. and T. G. Northcote	1981
Steelhead	Dominance, growth	Circular tanks, flumes, outdoor stream channel	Berejikian, B. A. et al	2000
	Competition, behavior	Circular tanks, natural stream channel	Berejikian, B. A. et al	2001

Table 1 (Continued). List of studies reviewed covering a wide range of species and experimental designs.

Species	Study Theme	Study apparatus	Author	Year
	Agonistic behavior	Rearing tanks, natural stream channel	Berejikian, B. A. et al	1996
	Growth and survival	Experimental stream channels	Fraser, F. J.	1969
	Dominance, size and experience	Aquaria	Abbott, J. C., et al.	1985
	Food related diurnal distribution	Stream aquaria	Chapman, D. W. and T. C. Bjornn	1969
	Behavior and physiology	Rectangular fiberglass tanks	Kelsey, D. A., et al.	2002
Trout?	Competition, delayed mortality	Instream barriers	Miller, R. B.	1958

Table 9. List of attributes for different types of artificial systems used to study behavioral interactions of fishes.

Aquaria	Tanks or troughs	Artificial streams	In-stream enclosures
Simple	Simple	Complex	Complex
Low cost	Low cost	Moderate to high costs	Moderate to high costs
Good potential for replication	Good potential for replication	Fair potential for replication	Low to fair potential for replication
Good control of expt. variables	Good control of expt. variables	Good control of expt. variables	Fair control of expt. variables
Minimal resource needs (e.g., space, water)	Moderate resource needs	Moderate to high resource needs	Low resource needs
Best for single or paired fish	Can be used for single, paired, or small groups of fish	Best for groups of fish	Best for groups of fish
Good viewing of interactions	More difficult viewing of interactions	Good viewing of interactions	More difficult viewing of interactions
Low ecological realism	Low ecological realism	Moderate to high ecological realism	High ecological realism
			Prone to natural disasters

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