The Entrainment and Screening of Returning and Postspawning Adult Salmonids at Irrigation Canals of the Umatilla River, Oregon

William G. Simpson*

Abernathy Fish Technology Center, U.S. Fish and Wildlife Service, 1440 Abernathy Creek Road, Longview, Washington 98632

Present address: Columbia River Fish and Wildlife Conservation Office, U.S. Fish and Wildlife Service, 1211 S.E. Cardinal Court Suite 100, Vancouver, Washington 98683

Abstract

Anadromous salmonids can be vulnerable to entrainment at diversion intake structures on streams, effectively trapping fish in irrigation canals and removing them from a population. Currently little is known about how the differences in timing and direction of movement among adult salmonids contribute to their risk of entrainment and how successful they are at escaping irrigation canals. Potential routes of escape include passing against water currents and through the headgate of an irrigation canal intake or by navigating through screen and bypass infrastructure primarily designed to return juvenile fish to a stream. In this study, passive integrated transponders (PIT tags) were used to track the movement of adult Chinook Salmon *Oncorhynchus tshawytscha* (*n* = 573), Coho Salmon *Oncorhynchus kisutch* (*n* = 39), and anadromous Rainbow Trout *Oncorhynchus mykiss* (steelhead, *n* = 853) as they entered areas of the Umatilla River basin (Oregon) with irrigation canals and as they attempted to escape irrigation canals after entrainment. Although adult steelhead and spring Chinook Salmon often encountered diversions at similar times, the vast majority of entrained adults were steelhead (94%). Between 2% and 8% of adult steelhead observed entering the area were entrained. The entrainment of steelhead was strongly associated with downstream movements and Umatilla River discharge below 40 m^3^/s. Many downstream-moving steelhead were postspawning fish (kelts). As a result, vulnerability of anadromous adults to entrainment differed by species due to the direction of their movements and how these movements coincide with canal operations and river flows. It is unlikely that the screened irrigation canals acted as an ecological sink; the majority of adult salmonids approached the canal headgate after becoming trapped in the canal and did not successfully return to the Umatilla River using this route. Unscreened irrigation canals elsewhere may disproportionally trap downstream steelhead, like postspawning kelts, due to their propensity for entrainment and their difficulties escaping through the water intakes of irrigation canals. In streams with anadromous salmonids, fish screen and bypass infrastructure primarily designed to eliminate the permanent entrainment of juvenile fish can also prevent the removal of adult fish that may reproductively contribute to the population.

Keywords: entrainment; fish-screening; irrigation canals

Received: July 11, 2017; Accepted: March 24, 2018; Published Online Early: March 2018; Published: June 2018

Citation: Simpson WG. 2018. The entrainment and screening of returning and postspawning adult salmonids at irrigation canals of the Umatilla River, Oregon. *Journal of Fish and Wildlife Management* 9(1):285-295; e1944-687X. doi:10.3996/072017-JFWM-058

Copyright: All material appearing in the *Journal of Fish and Wildlife Management* is in the public domain and may be reproduced or copied without permission unless specifically noted with the copyright symbol ©. Citation of the source, as given above, is requested.

The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

* Corresponding author: william_simpson@fws.gov
Introduction

The alteration and simplification of riparian habitats have adversely affected native salmonids in the Columbia River basin of the western United States (Thurow et al. 1997). These changes have contributed to a substantial number of Pacific salmon populations being extirpated or listed as threatened or endangered under the U.S. Endangered Species Act (ESA 1973, as amended; Nehlsen et al. 1991). Migratory salmonids can be particularly sensitive to riparian alteration because they can use habitats that are dispersed across large geographic scales. Entire assemblages of migratory fishes can be altered by obstructions on major rivers or at the base of tributaries because many life-history types, populations, and species of fish can use the same migration corridors when traversing between habitats (Rieman and Dunham 2000). For instance, the direct influence of large hydroelectric dams on both juvenile and adult migratory salmonids in the Pacific Northwest has been thoroughly investigated, and both structural and operational modifications are frequently used to mitigate for these effects (Connor et al. 1998; Muir et al. 2001b; Budy et al. 2002). Although water diversion structures greatly outnumber hydroelectric facilities in the Pacific Northwest, much less is known about the effect of water diversion dams on populations of anadromous salmonids (Moyle and Israul 2005). Water diversion canals that entrain fish and dewaters streams can act as an ecological sink that restricts fish movement or kills fish upon canal dewatering (Rahel 2013). Such habitat fragmentation can adversely affect fish populations (Morita et al. 2000; Morita and Yamamoto 2002).

Efforts to evaluate population-level effects of irrigation canals on anadromous salmonids are often focused on the entrainment of juvenile life stages. Studies indicate that the percentage of juvenile fish entrained into canals can be high on a basinwide scale despite variability among individual diversions (Simpson and Ostrand 2012; Walters et al. 2012). Removals of adult salmonids from rivers by surface water diversions have not been as thoroughly investigated and could be more detrimental than the removal of juveniles from a population perspective because most life cycle mortality occurs before fish return to their spawning grounds (Bradford 1995; Buchanan and Skalski 2010). Unscreened irrigation canals with traditional headgate structures at canal intakes have acted as population sinks for adult resident salmonids (Gale 2005; Roberts and Rahel 2008). Fish can have difficulty escaping through headgate structures before the seasonal dewatering of canals. The percentage of adult resident salmonids entrained at water diversions may be related to the timing and type of movement these fish exhibit (Schrank and Rahel 2004; Gale et al. 2008). Even less is known about how vulnerable species of adult anadromous salmonids are to entrainment and how fish behavior and river conditions influence this vulnerability.

Fortunately many irrigation canals are screened in the Columbia River basin to prevent the permanent loss of entrained fish. Large-scale screening efforts can effectivity reduce the direct mortality of juvenile anadromous salmonids (Simpson and Ostrand 2012) because most criteria for screen construction and evaluation have traditionally focused on juvenile fish (Neitzel et al. 1991; Cameron et al. 1997; McMichael et al. 2004). Adults of salmonids exhibiting resident life histories, such as Cutthroat Trout Oncorhynchus clarkii, have used screen and bypass infrastructure to escape irrigation canals after entrainment (Gale et al. 2008). However, it is unknown how efficient relatively larger anadromous adults are at using screen bypass tubes and other infrastructure to return to streams, especially if they are unable or unwilling to escape through canal headgate structures. Individuals may resist the use of submerged and confined fish-bypass tubes at the downstream end of irrigation canals because adult anadromous salmonids often exhibit positive rheotaxis and prefer to pass structures using surface water (Arnekleiv et al. 2007; Wertheimer 2007).

The Umatilla River, Oregon, is an example of a drainage in the Columbia River basin with a large network of screened irrigation diversions. Considering that mid-Columbia River steelhead (Oncorhynchus mykiss, or anadromous Rainbow Trout) are federally listed as threatened in the mid-Columbia River basin (NOAA 2006) and the desired maintenance of previously reintroduced Coho Salmon Oncorhynchus kisutch and Chinook Salmon Oncorhynchus tshawytscha stocks in the Umatilla River (Phillips et al. 2000), it is important to understand how irrigation diversion networks may adversely affect these fish. Screen and bypass infrastructure appear to be effective at returning entrained juvenile steelhead to the Umatilla River (Simpson and Ostrand 2012). Unfortunately little is known about the vulnerability of adult anadromous salmonids to entrainment at irrigation structures and whether fish screens are effective at preventing the entrapment of these fish. Therefore, I 1) assessed vulnerability of adult salmonids to entrainment by examining how adult migration timing coincides with the operations of irrigation canals, Umatilla River flows, and the directional movement of fish; 2) compared entrainment among species of adult salmon that migrate at different times; and 3) determined whether entrained adults can successfully navigate through fish bypass infrastructure at fish screens and return to the Umatilla River.

Study Area

The Umatilla River basin is in northeastern Oregon and drains an area of approximately 6,000 km². The source of the river and its tributaries are in the forested Blue Mountains, from which the river travels 185 km northwest into shrub-steppe plains before it converges with the Columbia River. Agricultural lands on these arid plains are provided water by several irrigation projects initiated in the early 20th century. Mountain snowmelt and rain usually results in peak river flows in spring. In late summer and early autumn flows are low and water temperatures are high.
I focused on adult salmonids passing upstream of Three Mile Falls Diversion Dam (river kilometer [rkm] 4.8) and the later canal entrainment of these fish at Maxwell (rkm 23.8) and Feed (rkm 47.0) diversion dams (Figure 1). Three Mile Falls and Feed diversion dams are equipped with ladders to pass adult salmonids. Maxwell and Feed diversion dams are notched to assist with salmonid passage. The diversions are described in more detail by Simpson and Ostrand (2012) and represent three of the six major diversion dams (others include Dillon, Westland, and Stanfield) on the Umatilla River. Within the irrigation canals a series of rotary drum screens are angled obliquely to water flow to guide entrained fish into a submerged bypass tube that returns them to the Umatilla River (Figure 2).

Maxwell and Feed canals differed in watered area, diversion capacity, dewatering schedule, bypass size, and location. The watered area between the headgate and rotary drum screen was larger at Maxwell Canal (2.4 km × 5 m) than at Feed Canal (0.21 km × 16 m). The water diversion capacity of Maxwell Canal does not typically exceed 1.25 m³/s and the capacity of Feed Canal does not typically exceed 6.25 m³/s. Feed Canal was often dewatered between April and December, and Maxwell Canal was often dewatered between October and April.

Figure 1. Map of the Umatilla River basin, Oregon, illustrating the location of diversion dams and canals where the movement of adult salmonids tagged with passive integrated transponders (PIT) was monitored (squares) using submerged PIT antenna arrays from 2006 to 2013. Arrays were placed inside Maxwell and Feed irrigation canals to detect fish entrainment, and at Three Mile Falls Diversion Dam and Feed Diversion Dam to detect when adults were in the area and potentially available for entrainment at the diversions. Mean daily river discharge was measured at a stream gage (circle). Species of salmonids tagged and monitored included fall (autumn) and spring migrating Chinook Salmon *Oncorhynchus tshawytscha*, Coho Salmon *Oncorhynchus kisutch*, and anadromous Rainbow Trout *Oncorhynchus mykiss* (steelhead). The inset map shows the location of the Umatilla River basin relative to the Pacific Northwest.

Figure 2. Diagram of irrigation canal infrastructure that was monitored on the Umatilla River, Oregon, for the entrainment of adult salmonids tagged with passive integrated transponders (PIT) from 2006 to 2013. Movement of adult salmonids into Maxwell and Feed irrigation canals was detected using two PIT antenna arrays (PIT detectors) within the canal. The first upstream PIT detector near the canal headgate was designed to identify fish entering the canal during entrainment, and the second downstream PIT detector was placed adjacent to drum screens and fish bypass tubes designed to return entrained fish to the river. Species of salmonids tagged and monitored included fall (autumn) and spring migrating Chinook Salmon *Oncorhynchus tshawytscha*, Coho Salmon *Oncorhynchus kisutch*, and anadromous Rainbow Trout *Oncorhynchus mykiss* (steelhead).
The bypass tube diameter at Maxwell Canal was 0.61 m and the tube diameter at Feed Canal was 0.76 m. All anadromous salmonid species in the Umatilla River basin spawn upstream of both Maxwell and Feed diversion dams, but some Coho Salmon and autumn Chinook Salmon also spawn between Maxwell and Feed diversion dams.

Methods

Movement of PIT–tagged adult salmonids in the Umatilla River basin

I monitored the movement of fall (autumn) and spring Chinook Salmon, Coho Salmon, and steelhead implanted with 12-mm full-duplex passive integrated transponder (PIT) tags as fish travelled upstream toward their spawning grounds in the upper Umatilla River basin. All PIT-tag data are publicly available from the Columbia Basin PIT-tag Information System (www.ptagis.org, Data S1, Supplemental Material). I grouped salmonids by how they were PIT-tagged. One group of returning adults was originally PIT-tagged in the Umatilla River basin as juveniles (natives). The second group of returning adults was originally PIT-tagged as juveniles in other Columbia River basins (strays). The third group of returning adults was captured and PIT-tagged as adults outside the Umatilla River basin, but was last detected migrating up the Umatilla River (extrabasin). The first three groups of fish were detected while volitionally passing the PIT-tag antenna arrays (hereafter, PIT detectors) mounted in the adult ladder (only route for upstream movement) and the juvenile bypass system (JBS, downstream movement) of Three Mile Falls Diversion Dam. The final group of returning adults was captured at the Three Mile Falls Diversion Dam adult trap where they were PIT-tagged and released into the dam forebay (intrabasin). The first three groups of returning adults were tagged as part of this final group of returning adults. Adult salmonids passing the adult ladder at Three Mile Falls Diversion Dam during low returning adults. Adult salmonids passing upstream of the entrainment area were identified by a PIT detector at Feed Diversion Dam (November 2008 through 2013). The antennas of the PIT detector were installed against the horizontal floor of the dam notch (pass-by, two 0.9 m × 2.9 m antennas), and over each of the two downstream orifices of the adult ladder at Feed Diversion Dam (swim-through orientation, Zydlewski et al. 2006). All PIT-tag antenna arrays used to detect tagged fish in the Umatilla River basin are operated and powered using a Destron Fearing FS1001M transceiver. I used the overlap between the timing of canal operations and the timing of PIT-tag detections at Three Mile Falls and Feed diversion dams as a general indicator of how frequently canals were operating while these adults were in the area and potentially available for entrainment.

I classified adult steelhead as kelts (postspawning steelhead) if they were detected at downstream Columbia River dams after detection in the Umatilla River, or if they were detected migrating downstream through the JBS at the Three Mile Falls Diversion Dam on or after 20 April. The antenna of this PIT detector was mounted vertically to the JBS orifice (swim-through, dimensions 2.0 m × 1.9 m). Although kelts pass the JBS before this date, I chose it as a conservative indicator of kelt passage because telemetry data suggest that the majority of adult steelhead that arrive at spawning tributaries and later pass downstream through the JBS as kelts do so after this date (88%; K. Costi, Confederated Tribes of the Umatilla Indian Reservation, unpublished data). Furthermore, the vast majority of steelhead have passed through the adult ladder at Three Mile Falls Diversion Dam before this date (98% of trapped fish, 95% of detected fish). I considered steelhead kelts vulnerable to entrainment when PIT detections at the JBS on or after this date coincided with the operation of Maxwell and Feed diversion dams. Subsampling of juvenile steelhead within the JBS allowed me to calculate a spring detection efficiency at the PIT detector (mean annual detection efficiency = 77%).

The entrainment and bypass of adult salmonids

A pair of PIT detectors were installed within both Maxwell and Feed canals and operated from 2006 to 2013. Each PIT detector consisted of an array of multiple vertically-mounted antennas (swim-through) that span the entire width of the canal. Antenna sizes ranged from 1.2 to 1.4 m tall and 3.2 to 5.2 m wide. Arrays were installed just downstream of the canal headgates to monitor fish entrainment and just upstream of the rotary-drum screens to detect fish encountering screen and bypass tube infrastructure (Figure 2). The number of antennas in each array was variable (Maxwell Canal headgate = 2, Maxwell Canal screen = 2, Feed Canal headgate = 6, Feed Canal screen = 5). I used the abundant spring detections of juvenile salmonids...
Table 1. The percentage of time that Maxwell and Feed irrigation canals were operating (diverting water) when adult salmonids tagged with passive integrated transponders (PIT) were detected approaching (detection at Three Mile Falls [TMF] Diversion Dam) and exiting (detection at Feed Diversion Dam) areas where fish were potentially vulnerable to entrainment at canals on the Umatilla River, Oregon. The passage of PIT-tagged salmonids was monitored at these facilities using submerged antenna arrays from 2006 to 2013. Salmonid species monitored include fall (autumn) and spring migrating Chinook Salmon *Oncorhynchus tshawytscha* (f. Chinook, sp. Chinook), Coho Salmon *Oncorhynchus kisutch*, and anadromous Rainbow Trout *Oncorhynchus mykiss* (steelhead). Adult steelhead detected moving downstream through the juvenile bypass system (JBS) at TMF from 20 April to June were considered kelts moving out of the area.

| Approaching canal area | Exiting canal area |
|------------------------|---------------------|
| **TMF Dam detections** | **Feed Dam detections** |
| **Maxwell Canal** | **Feed Canal** | **Maxwell Canal** | **Feed Canal** |
| f. Chinook | 46.2 | 0.0 | 8.6 | 0.0 |
| sp. Chinook | 100 | 9.5 | 100 | 12.3 |
| Coho | 18.4 | 0.0 | 5.6 | 0.0 |
| steelhead | 32.4 | 68.8 | 11.3 | 40.6 |

**TMF JBS detections**

| steelhead kelts | n/a | n/a | 100 | 11.8 |

entrained into the canal to determine the efficiency of canal PIT detectors (Maxwell Canal headgate = 69%, Maxwell Canal screen = 82%, Feed Canal headgate = 33%, Feed Canal screen = 40%). I calculated the percentage of adult fish that moved upstream into the area with irrigation diversions and were later entrained using the total number of the PIT-tagged adults moving upstream of Three Mile Falls Diversion Dam (released + detected volitionally passing the dam). This percentage of entrained fish does not account for any prespawn mortality and represents the minimum percentage of adult salmonids encountering the diversion that were entrained.

I estimated how long fish spent inside the canal by calculating the elapsed time between the first PIT detection at the headgate array and the last PIT detection at the screen array. Time elapsed between the first headgate detection and the first screen detection was an estimate of how long it took salmonids to reach the fish screen. Finally, I estimated how long salmonids spent in front of the fish bypass infrastructure by calculating the elapsed time between the first and last detection at the screen array. I categorized any steelhead detected upstream before entrainment or downstream after entrainment as moving downstream. I considered later detections of entrained adults elsewhere in Umatilla and Columbia River basins as confirmation that adults successfully returned to the Umatilla River.

Annual surveys (2007–2013) for PIT tags deposited by dead adult salmonids were conducted within dewatered irrigation canals in the summer or autumn. During the survey, two biologists scanned the canal bottom in a single pass using portable PIT-tag detection units (“PITpacks”; Hill et al. 2006). The PITpack consisted of a Destron Fearing full duplex transceiver (FS1001A or a FS2001F with a tuning box), a direct current battery to power the transceiver, and a polyvinyl chloride antenna wand containing several wraps of wire. At the end of the antenna wand is an oval loop (0.6 m × 0.4 m) designed to detect PIT tags. I estimated the minimum detection efficiency of the PITpack surveys by examining the percentage of tags that were detected in more than one annual survey at Maxwell Canal because PIT tags can become buried or break down over time. The unbiased detection efficiencies of stationary PIT tags are expected to be high (p = 0.81–0.83; O’Donnell et al. 2010).

I used Umatilla River discharge measured at Bureau of Reclamation gaging station UMDO (rkm 40; Figure 1) to characterize river flows experienced by adult salmonids passing diversion dams during potential entrainment. I examined river discharge during potential entrainment at Maxwell Canal from canal activation (early April) to 5 June, and during potential entrainment at Feed Canal from canal activation (late November to early January) to dewatering (early April to mid-May). I compared the frequency distribution of mean daily river discharge (pooled across all years 2006–2013) between days when each adult salmonid species was entrained and days when there was no entrainment using a Kolmogorov–Smirnov test (K–S test).

**Results**

Vulnerability to entrainment differed by species and the timing of movement. Maxwell Canal diverted water <50% of the time when fall Chinook Salmon and Coho Salmon were entering (Three Mile Falls Diversion Dam detection) and exiting (Feed Diversion Dam detection) the entrainment area, and Feed Canal was not operating at this time (Table 1). Umatilla River discharge was relatively low while fall Chinook Salmon and Coho Salmon were detected passing Three Mile Falls Diversion Dam (Table 2). In contrast, when spring Chinook Salmon and steelhead kelts were in the entrainment area, Maxwell Canal was always diverting water (100%; Table 1). Umatilla River discharge was relatively higher and more variable while spring Chinook Salmon and steelhead kelts were being detected at Three Mile Falls.
Diversion Dam compared with when other salmonids were migrating (Table 2). Upstream-migrating steelhead were the only salmonids regularly present when Feed Canal was operated (40.6–68.8%; Table 1). Only 0.8% of PIT-tagged adult steelhead passed the Three Mile Falls fish ladder on days when adult fish were trapped and hauled upstream of the entrainment area. Nineteen percent of PIT-tagged adult spring Chinook Salmon passed the fish ladder on days when adult fish were trapped and hauled upstream.

A total of 865 adult steelhead were either tagged at, or detected passing, the Three Mile Falls Diversion Dam adult ladder. Thirteen of these fish were later detected at upstream Columbia River fish ladders or at downstream tributaries without evidence of moving upstream of Three Mile Falls Diversion Dam, and only one adult steelhead made such movements after an upstream detection on the Umatilla River. Proportionally more of the excluded fish were from the stray group ($N_{\text{strays}} = 3, 8.1\%$) than the other three groups ($N_{\text{natives}} = 0, 0\%; N_{\text{intrabasin}} = 8, 1.2\%; N_{\text{extrabasin}} = 2, 3.8\%$). I detected only one adult steelhead reascending the adult ladder at Three Mile Falls Diversion Dam after passing downstream through the JBS.

I identified the entrainment of 30 adult steelhead by using PIT detectors at Maxwell and Feed canals from 2006 to 2013, representing the entrainment of between 1.6% and 7.8% of all steelhead observed at Three Mile Falls Diversion Dam (Table 3). The majority of entrained steelhead were diverted into Maxwell Canal ($N = 24, 80\%$). All but one steelhead were entrained at Maxwell Canal between the first week of April and the first week of June.

### Table 2. Umatilla River flow at gauging station UMDO over the range of days adult salmonids tagged with passive integrated transponders (PIT) most frequently passed at Three Mile Falls Diversion Dam (TMF) from 2006 to 2013. The passage of PIT-tagged salmonids at this facility was monitored using submerged antenna arrays from 2006 to 2013. Salmonid species monitored include fall (autumn) and spring migrating Chinook Salmon *Oncorhynchus tshawytscha* (f. Chinook, sp. Chinook), Coho Salmon *Oncorhynchus kisutch*, and anadromous Rainbow Trout *Oncorhynchus mykiss* (steelhead). Adult steelhead detected moving downstream through the juvenile bypass system at TMF from 20 April to June were considered kelts.

| Species       | Date range | 1st quartile flow (m$^3$/s) | Median flow (m$^3$/s) | 3rd quartile flow (m$^3$/s) |
|---------------|------------|------------------------------|-----------------------|-----------------------------|
| f. Chinook    | 10 Sep–25 Nov | 3.6                          | 4.6                   | 6.1                         |
| sp. Chinook   | 20 Apr–30 Jun | 4.9                          | 13.5                  | 39.7                        |
| Coho          | 15 Sep–26 Nov | 3.7                          | 4.6                   | 6.0                         |
| steelhead     | 7 Sep–30 Apr  | 5.2                          | 8.8                   | 20.0                        |
| steelhead kelts | 20 Apr–1 Jun | 7.9                          | 22.3                  | 52.1                        |

### Table 3. Number of adult salmonids tagged with passive integrated transponders (PIT) and entrained into Maxwell and Feed irrigation canals on the Umatilla River, Oregon. The entrainment of PIT-tagged salmonids was detected within the canal using submerged antenna arrays adjacent to the canal headgate and canal screens from 2006 to 2013. Salmonid species monitored include fall (autumn) and spring migrating Chinook Salmon *Oncorhynchus tshawytscha* (f. CHI, sp. CHI), Coho Salmon *Oncorhynchus kisutch* (COH), and anadromous Rainbow Trout *Oncorhynchus mykiss* (STH [steelhead]). The number of adults observed at Three Mile Falls Diversion Dam (TMF) includes fish detected with submerged antenna arrays during upstream passage and fish captured and tagged at the adult fish ladder trap. The number of adult fish observed at TMF that were later detected as entrained represents the minimum percentage of fish entrained by these irrigation canals.

| Species | Group   | Adults observed at TMF (n) | All entrained adults (n) | Entrained adults observed at TMF (n) |
|---------|---------|-----------------------------|--------------------------|--------------------------------------|
|         | Natives | Feed | Maxwell | Feed | Maxwell | Total |
| f. CHI  | 29      | 0    | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Strays  | 26   | 0       | 1 (3.8%) | 1 (3.8%) | 1 (3.8%) |
|         | Intrabasin | 193  | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Extrabasin | 91   | 0       | 1 (1.1%) | 1 (1.1%) | 1 (1.1%) |
|         | Total   | 339  | 0       | 2 (0.6%) | 2 (0.6%) | 2 (0.6%) |
| sp. CHI | 41      | 0    | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Strays  | 6    | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Intrabasin | 101  | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Extrabasin | 86   | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Total   | 234  | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
| COH     | 13      | 0    | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Strays  | 0    | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Intrabasin | 0    | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Extrabasin | 26   | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
|         | Total   | 39   | 0       | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
| STH     | 123     | 1    | 10      | 0 (0.0%) | 7 (5.7%) | 7 (5.7%) |
|         | Strays  | 34   | 0       | 3 (2.9%) | 1 (2.9%) | 1 (2.9%) |
|         | Intrabasin | 644  | 4       | 6 (0.9%) | 6 (0.9%) | 10 (1.6%) |
|         | Extrabasin | 51   | 1       | 5 (5.9%) | 5 (2.0%) | 4 (8.7%) |
|         | Total   | 852  | 6       | 24 (2.0%) | 17 (2.0%) | 22 (2.6%) |
Umatilla River discharge exceeded 40 m$^3$/s on 34% of the observed at Maxwell Canal (K–S test, discharge relative to days when no entrainment was associated with lower (i.e., negatively skewed) Umatilla River discharge. Entrainment of PIT-tagged adult steelhead was associated with adult entrainment at Feed Canal and Maxwell Canal, respectively, on or after 20 April (N = 5). One downstream-moving steelhead was detected at the JBS before 20 April. Downstream movement of two adult steelhead entrained at Maxwell Canal was established by detecting them upstream at Feed Diversion Dam before entrainment, one of which was entrained after 20 April.

The amount of time adult steelhead spent navigating the irrigation canal once entrained was variable. The median time entrained adult steelhead were detected inside Maxwell Canal was 326 min (range = 54–10,054 min; N = 18). Half of these steelhead spent <8% of the travel time in front of the fish screen, and these fish spent less time in the canal (median = 93 min, N = 9). The other half spent >40% of their travel time in front of the fish screen, resulting in more time inside the canal (median = 447 min, N = 9). The time it took entrained steelhead kelts to reach the screen at Maxwell Canal was short (median = 57 min, N = 8) relative to the time spent in front of the screens (median = 381 min). Steelhead not detected outside the canal after entrainment took longer to reach the screens (median = 162 min, N = 10), but appeared to spend less time in front of the bypass (median = 2 min). The travel time of the single fish in Feed Canal that was detected at both the headgate and screen was 386 min. Seven steelhead were detected making an upstream approach to Maxwell Canal headgate after entrainment, and three of these fish had approached the screen before moving back up the canal to encounter the headgate. However, all seven of these steelhead were last detected at the fish screen. One persistent adult steelhead encountered the headgate structure 147 times and returned to the headgate structure from the fish screen 5 times. Regardless, most adult steelhead were last detected approaching the fish bypass facilities after entrainment (N = 27, 90%). Many entrained steelhead were later observed at Umatilla or Columbia River PIT detectors (N = 14, 47%), indicating that a large number of fish successfully navigated through the fish bypass system and were returned to the Umatilla River.

Two fall Chinook Salmon jacks (fish that spent 1 y in the ocean) were entrained at Maxwell Canal in late September. One fish was entrained when the Umatilla River discharge was at 2.6 m$^3$/s and was later observed at the fish-screen PIT detector. This fall Chinook Salmon returned to the headgate structure before its last detection at the screen. The second fall Chinook Salmon was entrained when the Umatilla River discharge was at 4.1 m$^3$/s and was later detected in the Umatilla River. No adult Coho Salmon or spring Chinook Salmon were detected as entrained in either canal.

No PIT tags associated with adult salmonids were detected during the annual surveys inside dewatered canals (Maxwell and Feed canals) using portable PIT-tag detection units. These surveys did detect PIT tags associated with juvenile salmonids in Maxwell Canal (N = 45) and in Feed Canal (N = 12). Ten (22%) of the PIT
tags detected in Maxwell Canal were observed over multiple years.

Discussion

Fish screen and bypass infrastructure can be a useful tool for maintaining river connectivity for entrained fishes and thus help mitigate some of the detrimental impacts of aquatic habitat fragmentation on fish populations (Gale et al. 2008; Roberts and Rahel 2008). However, the effectiveness of screens designed to prevent fish entrapment in irrigation canals is often not monitored after their installation (Moyle and Israel 2005). Irrigation canals fitted with rotary drum screens did not appear to act as a habitat sink for adult anadromous salmonids in the Umatilla River despite the subsurface orientation of the bypass designed primarily to return juvenile salmonids to the river. The majority of entrained adult steelhead and fall Chinook Salmon were detected encountering the fish screens after successfully passing through the unscreened portion of Maxwell and Feed canals. The proficiency with which many steelhead entrained into Maxwell Canal found the fish screens that reside far downstream of the headgate structure could be related to the active downstream movement salmonid kelts often exhibit (Arnekleiv et al. 2007; Hedger et al. 2009). Many adult salmonids were detected in the Umatilla and Columbia rivers after entrainment despite the poor probability of PIT-tag detection commonly documented at Columbia River dams due to the emphasis of passing fish through dam spillways that are lacking PIT detectors (Muir et al. 2001a; McMichael et al. 2010); and no adult salmonids were observed as stranded or killed inside the irrigation canals with portable PIT detectors. Similarly, rotary drum screens have largely prevented the trapping of juvenile salmonids in irrigation canals (Simpson and Ostrand 2012) and the trapping of smaller potamodromous adult salmonids in irrigation canals has been prevented using vertical fixed-plate screens (Gale et al. 2008).

Canals without screen and bypass infrastructure might act as an ecological sink for downstream-moving steelhead and kelts (Rahel 2013). Fish that approached the headgate at Maxwell Canal were not successful at returning to the river through the water intake and ultimately moved downstream through the fish bypass to escape the canal. The declining physiological condition often associated with salmonid kelts may have exacerbated the difficulty some downstream-moving steelhead had passing the high flow velocities at headgate structures after entrainment. Headgate structures have also prevented the escape of potamodromous salmonids from unscreened irrigation canals. When these structures restricted the return of fish to their river of origin a substantial percentage of entrained adult salmonids can be killed (77%, Roberts and Rahel 2008) after canals are dewatered. Conservation projects are now capturing and rearing iteroparous steelhead kelts to boost their survival and gonad regeneration in order to increase their reproductive contribution to certain vulnerable steelhead populations (reconditioning; Hatch et al. 2013). As a result, unscreened irrigation canals that trap steelhead kelts may detrimentally reduce the local availability of stock for such programs.

Some steelhead were documented stalling in front of the screen and bypass infrastructure for a significant period of time before returning to the Umatilla River. Downstream-moving adult salmonids are often observed as surface-oriented (Hedger et al. 2009) and navigate surface bypasses at dams quickly and efficiently (Arnekleiv et al. 2007; Wertheimer 2007; Scruton et al. 2008). Long bypass times for some entrained steelhead could be due to the subsurface orientation of the bypass tube. The low flow velocities used in the immediate vicinity of fish screens to prevent screen impingement of juvenile salmonids (McMichael et al. 2004) may also slow adult steelhead from orienting toward the bypass tube. Regardless, the delay in passage observed for downstream-moving steelhead and kelts navigating bypass infrastructure at Umatilla River diversions may have detrimental effects. The body condition of salmonid kelts declines as musculature is degraded and energy reserves are exhausted during their downstream migration (Booth et al. 1997; Keefer et al. 2008), so any delay in the onset of ocean feeding that could play a role in their physiological recovery (Evans et al. 2008; Hedger et al. 2009; Hatch et al. 2013; Penney and Moffitt 2014) might be detrimental to their survival. The survival of steelhead kelts has been poor during low flows on the Columbia River (Wertheimer and Evans 2005), and kelts that are barged downstream to avoid dam passage and reach the estuary more quickly have higher rates of return than kelts migrating in-river (Evans et al. 2008). The migration rate of steelhead kelts in the Columbia River basin is slower than kelts in other basins unimpeded by dams (English et al. 2006), and the results from this study suggest that entrainment at a screened irrigation diversion may further delay the migration of some kelts already impeded by Columbia River basin hydropower projects and their associated reservoirs (Wertheimer and Evans 2005; Wertheimer 2007).

Any detrimental effects that surface water diversions have on fish can also be minimized by hindering connectivity between rivers and irrigation canals at the headgate. Curtailing the movement of fish through surface water intakes can often be accomplished through changes in canal operations. Negative flow–entrainment relationships likely vary among irrigation diversions based on differences in localized fish movements, the timing of canal operations, and river geomorphology adjacent to irrigation structures (Moyle and Israel 2005; Post et al. 2006; Simpson and Ostrand 2012; Walters et al. 2012). The entrainment of adult salmonids on the Umatilla River was variable and based upon how a species’ migrational timing coincides with water withdrawals and river flows. Maxwell and Feed canals often were operated intermittently in the autumn, and as a result few autumn-migrating fish (Coho Salmon or fall Chinook Salmon) were entrained while traveling upstream despite low Umatilla River flows. In contrast, spring-migrating fish (steelhead kelts and spring Chinook Salmon) simultaneously encountered an operating Max-
well Canal during higher but variable flows between April and June. Many adult steelhead were entrained at this time, but only one was entrained during high river discharge (>40 m³/s). As a result, adult entrainment might be minimized by operating a canal during higher flows, or by entraining less water (i.e., minimizing the percentage of river flow entrained into the canals) when river levels are relatively low.

The overall physical characteristics, condition, and behavior of a fish species could also influence an individual’s vulnerability to entrainment. For example, larger fish capable of higher swimming speeds may be better equipped to avoid entrainment (Gale 2005; Post et al. 2006), although size distributions of entrained and nonentrained fish are not always different (Simpson and Ostrand 2012; Mussen et al. 2014). The entrainment of juvenile salmonids at JBS facilities on hydroelectric dams can be dependent on the condition of individual fish (Hostetter et al. 2015). I observed that entrainment was most frequently associated with adult steelhead moving downstream. No upstream-migrating spring Chinook Salmon were entrained at Maxwell Diversion Dam despite their passage coinciding with the downstream movement of steelhead, and fewer steelhead were entrained at Feed Canal that often operated when few kelts are traveling downstream (December through March). Entrainment may not be a result of the direction of movement itself because many of these downstream-moving steelhead were confirmed to be postspawning kelts. The body condition of emaciated steelhead kelts can result in poor swimming abilities relative to individuals on their upstream migration (Booth et al. 1997). As a result, kelts may be particularly vulnerable to entrainment at hydroelectric and diversion dams (Scrubton et al. 2002). Entrainment of high percentages of postspawning potamodromous salmonids have been observed using radio telemetry. In western Wyoming, 23% of postspawning Bonneville Cutthroat Trout were entrained into an irrigation canal (Schrank and Rahel 2004); and in Montana, 79% of westslope Cutthroat Trout that moved downstream of where they were tagged on spawning grounds were later entrained (Gale et al. 2008). More research is needed to determine empirically how the body condition of fish influences their vulnerability to entrainment at surface water diversions.

Many salmonids inhabiting the arid interior of the Columbia River basin exhibit anadromous life histories that often require adult fish to navigate past complexly operated networks of irrigation diversions. On the Umatilla River, fish screen and bypass infrastructure that are common to the Columbia River basin and designed for juvenile salmonids appeared effective at preventing the permanent loss of adult salmonids to irrigation canals. Canal screening is expensive and requires maintenance. My results suggest that when managers are prioritizing spending and are evaluating the costs and benefits of screening, that it is appropriate to consider survival benefits to adult steelhead, especially when steelhead kelts are seen as an important contributor to fish reproduction in a population. Further study into how body condition influences fish entrainment and how delayed passage at screens indirectly affects fish may assist managers making choices about water management or screening infrastructure that would minimize fish entrainment and its potential effects on fish.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

**Data S1.** Detection histories of passive integrated transponder (PIT) -tagged adult salmonids observed in the Umatilla River basin, Oregon, from 2006 to 2013. Found at DOI: http://dx.doi.org/10.3996/072017-JFWM-058.S1 (5920 KB CSV).

Acknowledgments

I thank C. Sater, K. Steinke, J. Hanson, C. Contor, and K. Costi for their assistance with this study. I also thank A. Gannam, the Editors, and three reviewers for suggestions that greatly improved earlier versions of the manuscript. The U.S. Bureau of Reclamation provided funding for this study.

Any use of trade, product, website, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Arnekleiv JV, Kraabol M, Museth J. 2007. Efforts to aid downstream migrating Brown Trout (*Salmo trutta L.*) kelts and smolts passing a hydroelectric dam and a spillway. *Hydrobiologia* 582:5–15.

Booth RK, Bombardier EB, McKinley RS, Scruton DA, Goosney RF. 1997. Swimming performance of postspawning adult (kelts) and juvenile (smolts) Atlantic Salmon, *Salmo salar*. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2406.

Brodie MJ. 1995. Comparative review of Pacific salmon survival rates. Canadian Journal of Fisheries and Aquatic Sciences 52:1327–1338.

Buchanan RA, Skalski JR. 2010. Using multistate mark-recapture methods to model adult salmonid migration in an industrialized river. Ecological Modelling 221:582–589.

Budy P, Thiede GP, Bouwes N, Petrosky CE, Schaller H. 2002. Evidence linking delayed mortality of Snake River salmon to their earlier hydrosystem experience. North American Journal of Fisheries Management 22:35–51.

Cameron WA, Knapp SM, Carmichael RW. 1997. Evaluation of juvenile salmonid bypass facilities and passage at water diversions on the lower Umatilla River. Bonneville Power Administration, Final Report, Portland, Oregon. Available: https://www.cbfish.org/
Entrainment and Screening of Adult Salmonids

W.G. Simpson

Journal of Fish and Wildlife Management | www.fwspubs.org

June 2018 | Volume 9 | Issue 1 | 294

PiscesPublication.mvc/SearchByTitleDescriptionAuthor
OrDate (February 2018).

Connolly PJ, Jezerek IG, Martens KD. 2008. Measuring the performance of two stationary interrogation systems for detecting downstream and upstream movement of PIT-tagged salmonids. North American Journal of Fisheries Management 28:402–417.

Conner WP, Burge HL, Bennett DH. 1998. Detection of PIT-tagged subyearling Chinook Salmon at a Snake River dam: implications for summer flow augmentation. North American Journal of Fisheries Management 18:530–536.

English KK, Robichaud D, Sliwinski C, Alexander RF, Koski WR, Nelson TC, Nass BL, Bickford SA, Hammond S, Mosey TR. 2006. Comparison of adult steelhead migrations in the mid-Columbia hydrosystem and in large naturally flowing British Columbia rivers. Transactions of the American Fisheries Society 135:739–754.

Evans AF, Wertheimer RW, Keefer ML, Boggs CT, Peery CA, Collis K. 2008. Transportation of steelhead kelts to increase iteroparity in the Columbia and Snake rivers. North American Journal of Fisheries Management 28:1818–1827.

Gale SB. 2005. Entrainment losses of westslope Cutthroat Trout into screened and unscreened irrigation canals on Skalkaho Creek, Montana. Master’s thesis. Bozeman: Montana State University. Available: http://scholarworks.montana.edu (February 2018).

Gale SB, Zale AV, Clancy CG. 2008. Effectiveness of fish screens to prevent entrainment of westslope Cutthroat Trout into irrigation canals. North American Journal of Fisheries Management 28:1541–1553.

Hatch DR, Fast DE, Bosch WJ, Blodgett JW, Whiteaker JM, Branstetter R, Pierce AL. 2013. Survival and traits of reconditioned kelt steelhead Oncorhynchus mykiss in the Yakima River, Washington. North American Journal of Fisheries Management 33:615–625.

Hedger RD, Hatin D, Dodson JJ, Martin F, Fournier D, Caron F, Whoriskey FG. 2009. Migration and swimming depth of Atlantic Salmon kelts Salmo salar in coastal zone and marine habitats. Marine Ecology Progress Series 392:179–192.

Hill MS, Zydlewski GB, Zydlewski JD, Gasvoda JM. 2006. Development and evaluation of portable PIT tag detection units: PITpacks. Fisheries Research 77:102–109.

Hostetler NJ, Evans AF, Loge FJ, O’Connor RR, Cramer BM, Frye D, Collis K. 2015. The influence of individual fish characteristics on survival and detection: similarities across two salmonid species. North American Journal of Fisheries Management 35:1034–1045.

Keefer ML, Wertheimer RH, Evans AF, Boggs CT, Peery CA. 2008. Iteroparity in Columbia River summer-run steelhead (Oncorhynchus mykiss): implications for conservation. Canadian Journal of Fisheries and Aquatic Sciences 65:2592–2605.

McMichael GA, Eppard MB, Carlson TJ, Carter JA, Ebberts BD, Brown RS, Weiland M, Ploskey GR, Harnish RA, Deng ZD. 2010. The juvenile salmon acoustic telemetry system: a new tool. Fisheries 35(1):9–22.

McMichael GA, Vucelick JA, Abernethy CS, Neitzel DA. 2004. Comparing fish screen performance to physical design criteria. Fisheries 29(7):10–16.

Morita K, Yamamoto S. 2002. Effects of habitat fragmentation by damming on the persistence of stream-dwelling char populations. Conservation Biology 16:1318–1323.

Morita K, Yamamoto S, Hoshino N. 2000. Extreme life history change of White-spotted Char (Salvelinus leucomaenis) after damming. Canadian Journal of Fisheries and Aquatic Sciences 57:1300–1306.

Moyle PB, Israel JA. 2005. Untested assumptions: effectiveness of screening diversions for conservation of fish populations. Fisheries 30(5):20–28.

Muir WD, Smith SG, Williams JG, Hockersmith EE, Skalski JR. 2001a. Survival estimates for migrant yearling Chinook Salmon and steelhead tagged with passive integrated transponders in the lower Snake and lower Columbia rivers, 1993–1998. North American Journal of Fisheries Management 21:269–282.

Muir WD, Smith SG, Williams JG, Sandford BP. 2001b. Survival of juvenile salmonids passing though bypass systems, turbines, and spillways with and without flow deflectors at Snake River dams. North American Journal of Fisheries Management 21:135–146.

Mussen, TD, Cocherell D, Poletto JB, Readon JS, Hockett Z, Ercan A, Bandeh H, Kavvas ML, Cech JJ, Fangue NA. 2014. Unscreened water-diversion pipes pose an entrainment risk to the threatened Green Sturgeon, Acipenser medirostris. PLoS ONE 9(1):e86321.

(NOAA) National Oceanic and Atmospheric Administration. 2006. Endangered and threatened species: final listing determinations for 10 distinct population segments of west coast steelhead. Federal Register 71(5 January 2006):834–862. Available: http://www.westcoast.fisheries.noaa.gov/publications/frn/2006/71fr834.pdf.

Nehlsen W, Williams JE, Lichatowich JA. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4–21.

Neitzel DA, Abernethy CS, Lusty EW. 1991. Evaluation of rotating drum screen facilities in the Yakima River basin, south-central Washington State. Pages 325–344 in Colt J and White RJ, editors. Fisheries bioengineering symposium. Bethesda, Maryland: American Fisheries Society. Symposium 10.

O’Donnell MJ, Horton GE, Letcher BH. 2010. Use of portable antennas to estimate abundance of PIT-tagged fish in small streams: factors affecting detection probability. North American Journal of Fisheries Management 30:323–336.

Penney ZL, Moffitt CM. 2014. Histological assessment of organs in sexually mature and post-spawning steelhead trout and insights into iteroparity. Reviews in Fish Biology and Fisheries 24:781–801.
Phillips JL, Ory J, Talbot A. 2000. Anadromous salmonid recovery in the Umatilla River basin, Oregon: a case study. Journal of the American Water Resources Association 36:1287–1308.

Post JR, van Poorten BT, Rhodes T, Askey P, Paul A. 2006. Fish entrainment into irrigation canals: an analytical approach and application to the Bow River, Alberta, Canada. North American Journal of Fisheries Management 26:875–887.

Rahel FJ. 2013. Intentional fragmentation as a management strategy in aquatic systems. BioScience 63:362–372.

Rieman BE, Dunham JB. 2000. Metapopulations and salmonids: a synthesis of life history patterns and empirical observations. Ecology of Freshwater Fish 9:51–64.

Roberts JJ, Rahel FJ. 2008. Irrigation canals as sink habitat for trout and other fishes in a Wyoming drainage. Transactions of the American Fisheries Society 137:951–961.

Scruton DA, Rahel FJ. 2004. Movement patterns in inland Cutthroat Trout (*Oncorhynchus clarkii utah*): management and conservation implications. Canadian Journal of Fisheries and Aquatic Sciences 61:1528–1537.

Scruton DA, McKinley RS, Kouwen N, Eddy W, Booth RK. 2002. Use of telemetry and hydraulic modeling to evaluate and improve fish guidance efficiency at a louver and bypass system for downstream-migrating Atlantic Salmon (*Salmo salar*) smolts and kelts. Hydrobiologia 483:83–94.

Scruton DA, Pennell CJ, Bourgeois CE, Goosney RF, King L, Booth RK, Eddy W, Porter TR, Ollerhead LMN, Clarke KD. 2008. Hydroelectricity and fish: a synopsis of comprehensive studies of upstream and downstream passage of anadromous wild Atlantic Salmon (*Salmo salar*), on the Exploits River, Canada. Hydrobiologia 609:225–239.

Simpson WG, Ostrand KG. 2012. Effects of entrainment and bypass at screened irrigation canals on juvenile steelhead. Transactions of the American Fisheries Society 141:599–609.

Thurow, RF, Lee DC, Rieman BE. 1997. Distribution and status of seven native salmonids in the interior Columbia River basin and portions of the Klamath River and Great basins. North American Journal of Fisheries Management 17:1094–1110.

[ESA] U.S. Endangered Species Act of 1973, as amended, Pub. L. No. 93-205, 87 Stat. 884 (Dec. 28, 1973). Available: https://www.fws.gov/endangered/esa-library/pdf/ESAall.pdf.

Walters AW, Holzer DM, Faulkner JR, Warren CD, Murphy PD, McClure MM. 2012. Quantifying cumulative entrainment effects for Chinook Salmon in a heavily irrigated watershed. Transactions of the American Fisheries Society 141:1180–1190.

Wertheimer RH. 2007. Evaluation of a surface flow bypass system for steelhead kelt passage at Bonneville Dam, Washington. North American Journal of Fisheries Management 27:21–29.

Wertheimer RH, Evans AF. 2005. Downstream passage of steelhead kelts through hydroelectric dams on the lower Snake and Columbia rivers. Transactions of the American Fisheries Society 134:853–865.

Zydlewski GB, Horton G, Dubreuil T, Letcher B, Casey S, Zydlewski J. 2006. Remote monitoring of fish in small streams: a unified approach using PIT tags. Fisheries 31(10):492–502.