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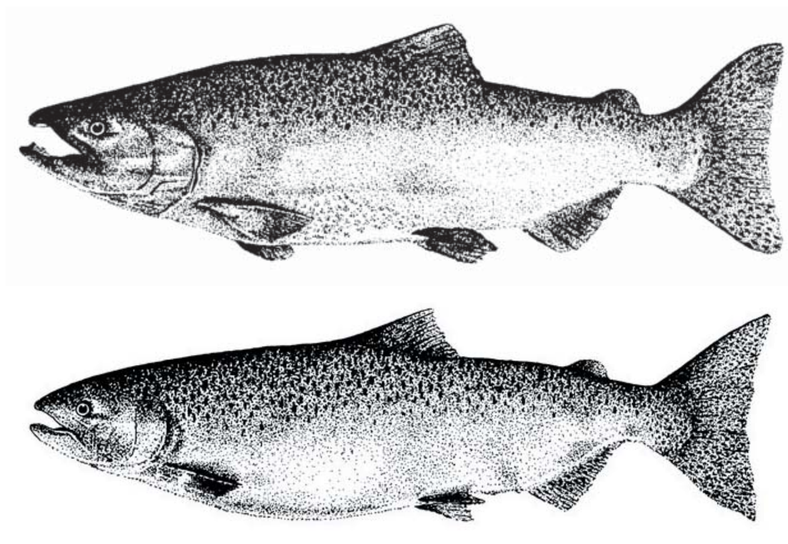
Migration and Movement Patterns of Adult Chinook Salmon (*Oncorhynchus tshawytscha*) Above Wells Dam



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Submitted To:
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Abstract

To evaluate summer/fall Chinook (*Oncorhynchus tshawytscha)* migration and movement patterns as part of the planning process for the Colville Confederated Tribes' planned Chief Joseph Hatchery, we radio tagged 291 adult Chinook that migrated above Wells Dam in 2005. The primary objectives of this study were to 1) identify whether the passage time of Chinook through the Wells Dam was related to spawning time and location, 2) if the proposed hatchery ladder was suitably placed to attract returning adults, and 3) identify areas where Chinook may be captured using selective fishing gears.

Both spawning location and spawning ground arrival date are related to passage date at Wells Dam but a relationship between spawning date and passage date at Wells was not observed. Earlier-arriving Chinook were more likely to migrate to the upper Okanogan and Similkameen rivers while later-arriving Chinook were more likely to migrate to the lower Okanogan River or remain in the mainstem Columbia River. Most radio tagged Chinook migrated up the Okanogan River when the temperature dropped below 20 degrees Celsius. However, there were tagged Chinook that migrated into the Okanogan River despite water temperatures of 20-25 degrees Celsius, temperatures typically considered lethal for salmonids. Data were collected so that in the future, genetic analysis can be used to further evaluate potential population differences.

Broodstock collection for the planned hatchery will use selective fishing methods. As a result, radio tag detections from fixed and mobile surveys were used to identify areas where fish aggregate. During 2005, suitable fishing gears were also identified. These gear/location combinations will be tested in the next two years for their ability to capture salmon with little harm and in good condition so that broodstock may be collected and species of concern, such as steelhead trout (*O. mykiss)* may be released with little harm.

Based on the results of this study, the ladder placement for the planned hatchery is suitable. Many Chinook hold at the base of Chief Joseph Dam and move back and forth between this area and the Colville Trout Hatchery, which is near the confluence of the Columbia and Okanogan Rivers. The proposed ladder position on the right side (north shore) of the Columbia River should draw in adults that hold in this area. Although 87.9% of the fish in this area spent time on both sides of the river, most fish (70.1%) were first detected on the right bank, indicating they moved into the area from the right bank (north shore) of the river. Further, although fish were found on both sides of the river throughout the study period, significantly more fish were found on the right bank. Once the hatchery is built and holds juvenile salmon, the ladder should provide additional incentive to adult Chinook as a chemical attractant.

Many radio tagged fish (41.8%) remained in the mainstem Columbia, indicating that deepwater spawning may be presently occurring in the area between Wells and Chief Joseph dams. Historic data describes spawning occurring in this area. As a result of this study, potential spawning areas have been identified for future investigation.

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Introduction

When the Grand Coulee Dam was completed in 1942, salmon could no longer migrate into the uppermost portion of the Columbia River. The subsequent building of the Chief Joseph Dam 82.3 km below Grand Coulee Dam created yet another impassable barrier to salmon migration. Although the Federal Government agreed to mitigation actions for the loss of anadromous fish production from these dams, the onset of the Second World War prevented their completion. Recently, these efforts have been renewed with the Colville Confederated Tribes' (CCT or Tribes) proposal to construct the Chief Joseph Hatchery to increase production of spring and summer/fall Chinook salmon (*Oncorhynchus tshawytscha*). Before the hatchery is built, questions about the proposed hatchery location, design, and management need to be further developed and answered. As a result, the Tribes and the Northwest Power and Conservation Council are participating in a three step planning process. The following goals emerged as part of this process:

1. Target the collection of locally adapted and genetically appropriate salmon for use as broodstock in the hatchery.
2. Establish hatchery broodstock that will supplement salmon populations in the Okanogan and Columbia rivers in agreement with the Hatchery and Genetic Management Plans as developed by the Tribes and co-managers.

Selecting the appropriate genetic or population unit is important because two or more population components may comprise the Chinook stock upstream from Wells Dam, with fish bound for either the Okanogan or Methow rivers included in that mixture. Further, many fish destined for Wells Hatchery or mainstem spawning areas below Wells Dam may overshoot the site and appear in the admixture upstream of the dam. Finally, it has been suggested that some fish may spawn in the mainstem Columbia River downstream from Chief Joseph Dam. One hatchery strategy is to supplement the Okanogan population. If this strategy is adopted, then acquiring broodstock from that genetic component will be crucial. Additional questions that need to be answered include:

- Is the Okanogan River Chinook population a single, fully integrated spawning unit?
- Is there a genetic basis for the later spawning of Chinook salmon in the lower Okanogan River that is related to run timing past Wells Dam?
- Is there a genetic basis for the population's continuum in spawn timing and location that should be considered in the design of the Chief Joseph Dam Hatchery Program broodstock and acclimation protocols?

Further, knowing where and when these fish migrate, where they congregate, and the extent that they are spatially separated from other population components in the upper Columbia will be critical for broodstock collection.

Part of the planning process requires the acquisition of basic biological information about Chinook migratory behavior. This information, particularly as it pertains to Chinook migration in the Methow River, will also meet the interests of the Columbia River Inter-Tribal Fisheries Commission (CRITFC) and the Yakama Nation to better understand Chinook behavior in this upper Columbia River tributary.

Study Goals and Objectives

The goal of this study was to address the following questions for fall/summer Chinook (hereafter referred to as Chinook unless specified otherwise):

1. Is there a relationship between passage time through the Wells Dam and spawning time and spawning location?
2. Is the proposed hatchery ladder in a suitable location for drawing adults into the hatchery and what is the fate of adults that congregate near the proposed ladder?
3. What are the migration and movement patterns of fish following their passage through Wells Dam and how will this influence the collection of broodstock?
4. Do hatchery and wild fish differ in their migration and movement behaviors? This question will be addressed as possible and provided that both hatchery and wild fish are tagged.

These objectives were addressed by:

1. Identifying the locations and arrival times of fish that spawn in the upper portion of the Columbia Cascade Province relative to their passage time at Wells Dam.
2. Describing the movement patterns of fish that migrate to Chief Joseph Dam to learn if they prefer particular areas and determine their final destinations.
3. Identifying areas where Chinook hold before they spawn and their migration patterns as they move into the Methow, Okanogan, and Similkameen tributaries.
4. Whenever possible, comparing the migration and movement patterns of hatchery- and wild-origin Chinook salmon.

1. Methods

Radio telemetry techniques were used to accomplish the study objectives. In addition, as fish and time permitted, scale samples were collected from fish suitable for radio tagging and jaw tags were applied to Chinook that did not receive radio tags to obtain additional information.

1.1 Sample size and distribution of tagged fish

Adult Chinook were collected and radio tagged at Wells Dam, then transported and released upstream. In addition, fish were jaw tagged over a five month period. These fish were distributed throughout the Chinook run timing (Table 1) to represent early, middle, and late migrants, with greater emphasis on the late migrants. The number of fish tagged each week was determined by the run forecast and previous year's run timing. A greater proportion of late migrants were tagged because historical information suggested that the Okanogan River receives higher densities of late run than early or middle run Chinook salmon (Stephen M. Smith, 2005, personal communication). When weekly tagging quotas were not met, the deficit was made up the following week.

Table 1. Radio tag goal by week for Chinook migration and movement study.

Week number	Dates	Radio tag goal
1	July 3 – 9	20
2	July 10 – 16	20
3	July 17 – 23	25
4	July 24 – 30	25
5	July 31 – August 6	20
6	August 7 – 13	15
7	August 14 – 20	15
8	August 21 – 27	15
9	August 28 – September 3	15
10	September 4 – 10	15
11	September 11- 17	10
12	September 18 – 24	10
13	September 25 – October 1	10
14	October 2 – 8	10
15	October 9 – 15	10
16	October 16 – 22	10
17	October 23 – 29	10
18	October 31- November 5	10
19	November 6 – 12	10

1.2 Fish capture

Chinook were trapped at the west and east ladders of Wells Dam (829.4 rkm and approximately 30 rkm downstream of the Columbia River confluence with the Okanogan River) using broodstock collection facilities already in place. During the first two weeks of the study, fish could only be collected at the west ladder because the hatchery programs needed all the fish moving through the east ladder for broodstock. (Both traps are located approximately half way up the fish ladders at pool 40). Fish ascending the ladder were blocked by a barrier fence when the traps were in operation, and forced to ascend an off-ladder trap via a steeppass Denil fishway that led to an upwell enclosure. Once inside the enclosure, fish were attracted down a sorting chute by jets of water located near the top of the chute. Fish were identified as they slid down the chute, and a decision was made to either divert them into a holding tank or to let them pass upstream of the trap. The traps differed in the way that fish were diverted into holding tanks. The east ladder trap had a 2.3 cubic meter holding tank while fish sampled from the west ladder were diverted to a hatchery raceway via a 76.2 cm enclosed water slide. Non-target species were shunted back to the ladder upstream of the trapping barrier.

Because wild fish will be used as broodstock for the planned Chief Joseph Hatchery, mostly unclipped Chinook, which were assumed to be wild fish, were collected and tagged for the radio tagging portion of the study. Scale samples were collected from wild fish to positively identify whether they were wild or hatchery fish that were unclipped. However, to evaluate potential differences between the two groups of fish, both unclipped and clipped (assumed to be hatchery and wild, respectively) Chinook were collected and tagged for the jaw tag portion of the study.

1.3 Tag description

1.3.1 Radio tags

We used digitally encoded 7 volt, model MCFT-7F radio transmitters (radio tags) developed by Lotek Engineering. This transmitter model has been used extensively in other adult Chinook telemetry studies and the tags can be encoded to omit a signal on any 1 of 5,300 unique channel/code combinations. Individual tags weigh 29 g in air and 13 g in water; have a diameter of 16 mm and a length of 83 mm. During typical operation, tags operate for 296 days with a burst rate of one pulse every five seconds. However, for this study they were programmed to cease functioning after 230 days (about 6 months) to minimize potential conflict with other telemetry studies. Ambient noise produced at the Chief Joseph Dam was expected to coincide with channels and codes within the desired transmission bandwidth (Shane Bickford, Douglas County PUD, personal communication January 2005), an so WDFW employees, a Lotek technician, and a Lotek engineer tested radio tags at various channels in February 2005. The test indicated that channels 148, 149, and 151 would work fine for this study. As the radio tagged fish migrated, they were detected at listening stations via fixed and mobile receivers.

1.3.2 Jaw tags

Jaw tags were also used to assess migration patterns. These metal tags had a plastic sheath with an imprinted number-letter combination so that individual fish could be identified. In addition, different sheath colors were used to assist in differentiating timing patterns of fish that passed Wells Dam and received a tag. Because only four jaw tag colors were available from the manufacturer (black, red, white, and yellow), each month a different tag color was used, and any fish captured in November received the same tag color as for October. When the tagged fish returned to hatcheries, were sampled on spawning grounds, or harvested, they were identified back to the individual fish with its date of passage through Wells Dam.

1.4 Tagging techniques

Fish receiving radio tags were subdued in a buffered carbon dioxide (CO_2) solution. The solution consisted of adding CO_2 gas through a high flow air stone until the pH of the water dropped approximately 1.3 points to a pH of 5.7. At this point, the CO_2 gas was turned off and baking soda was added as a buffer until the pH returned to neutral. Finally, oxygen (O_2) was added at a rate of 30 PSI and left on until the dissolved O_2 reached saturation. Once anesthetized, all Chinook were measured by fork length (cm) and an attempt was made at determining the sex of the fish by evaluating the shape of the mouth and fullness of the belly. Fish were identified as adipose marked (adipose fin clipped, indicating hatchery rearing as a juvenile) or adipose present (adipose fin intact, indicating natural rearing). In addition, the ladder the fish were collected in and the time that fish were tagged and released were also documented. Any visual marks on fish were noted, i.e. net marks, marine mammal marks, wounds, etc. Badly injured fish (bleeding, open wounds) were not radio tagged.

1.4.1 Radio tags

Wild Chinook (fish with adipose fins) received priority when enough fish were available to radio tag, although we did tag some hatchery Chinook (fish with a missing adipose fin) as well. Fish that were radio tagged had scale and DNA samples collected. Fish that met the proper criteria (suitable size for tagging and adipose fin present) were implanted gastrically with a radio tag, using a PVC pipe as a trochar. Prior to insertion, radio tags were checked to verify that they worked properly, and a rubber band was placed around the tag to roughen the surface (Keefer et al. 2004). Glycerol was added to the tag so it would more easily slide down the esophagus. The tags were inserted by feeding the antenna portion through the trochar, then inserting the trochar and tag into the esophagus until the tag passed the sphincter muscle of the stomach. Then, the trochar was removed and the antenna was bent backwards at the corner of the fish's mouth. Afterward, fish were placed into a 600 gallon tank on a transport truck, supplied with O_2 at a rate of 2-4 PSI, and allowed to recover.

1.4.2 Jaw tags

Fish that were to be jaw tagged were identified in the chute and shunted into the CO2 solution. Because they did not require such a strong dose, they were removed from the solution more quickly than fish that received radio tags. Fish receiving jaw tags were usually released back into the fish ladder after they had recovered (typically a matter of minutes). Some jaw tagged fish were transported and released above Wells Dam, but generally this was not possible because of limited space in the transport tank.

1.5 Release of radio tagged fish

Following their recovery, radio tagged Chinook were transported by truck and released at the Starr Boat Launch (approximately 4.4 km upstream of Wells Dam on the west side of the Columbia River) to minimize fallback. Arrangements were made to borrow a flatbed truck with a 2.3 cubic meter holding tank from the local WDFW Wells Hatchery. Fish were supplied with continuous oxygen until their release.

1.6 Monitoring

The migration of Chinook within the study area was assessed using mobile surveys and fixed listening stations. Detections from these made it possible to identify the approximate locations and timing for holding and spawning. The study area extended from Wells Dam to documented spawning areas within the Methow and Okanogan Basins as well as to the base of Chief Joseph Dam.

1.6.1 Mobile monitoring

Mobile monitoring was done using weekly or bi-weekly fixed-wing aircraft and boat surveys. Aerial survey results were used to plot the migration routes in weekly time steps and identify the approximate locations of final destinations of radio-tagged fish. We flew from the Wenatchee airport and listened for tags from Wenatchee to Chief Joseph Dam. Once fish entered into the tributaries, based on detections by the fixed receivers at the mouth of these tributaries, flight surveys tracked over the Okanogan, Similkameen, and Methow rivers to document holding areas and potential broodstock collection sites. Boat surveys occurred on a weekly basis on the mainstem Columbia River from the confluence of the Okanogan River to the Chief Joseph Dam tailrace. Their purpose was to provide greater spatial resolution regarding the positions and routes of tagged fish migrating through this zone and to identify with greater accuracy large concentrations of fish as a supplement to the data collected by the fixed monitoring stations.

1.6.2 Fixed monitoring

Fixed stations were deployed near the tailrace of the Chief Joseph Dam, along the Columbia River between the Okanogan River mouth and the Highway 17 Bridge, and at strategic locations on the Methow and Okanogan rivers. These stations enabled researchers to document whether fish preferred a particular shoreline, congregated in certain areas, and their general movement patterns over time (Table 2).

Table 2. Location and corresponding site number of fixed station receivers for Chinook migration and movement study.

Location	Site No.	River kilometer (rkm)
Chief Joseph Dam (Powerhouse)	01	864.5
South shore of Columbia River below Chief Joseph Dam	02	864.0
North shore of Columbia River below Chief Joseph Dam	03	864.0
Colville Trout Hatchery	04	859.0
Okanogan River at Riverside (from mouth of Okanogan)	05	65.8
Okanogan River near Monse bridge (from mouth of Okanogan)	06	10.7
Methow River near Pateros (from mouth of Methow)	07	3.0
Columbia R. below Wells Dam	08	817.0

1.6.3 Equipment

The Lotek SRX receiver was used for both mobile and fixed monitoring. This receiver was a multi-port, DSP compatible device and could monitor a 4 MHz bandwidth with a range of 148 to 152 MHz. The receivers were programmed to "listen" for tags at 6 second intervals, on each of four different channels, and on each connected antenna. All telemetry receivers were powered by either a 110- volt AC power supply or a solar panel backed up with two 12 volt DC RV batteries to ensure continuous operation. Fixed-site listening stations consisted of two or three 3-element Yagi antennas connected to a single SRX receiver. Unless noted, the antenna directed downstream and the antenna directed upstream aimed approximately 40 degrees off the shoreline to maximize detection. For stations where a third antenna was used, it was aimed across the channel, approximately centered between the upper and lower antennas. The following sections describe each of the fixed monitoring sites (also referred to as stations) and the mobile surveys in detail.

1.6.4 Methow and Okanogan rivers - monitoring stations

The purpose of locating the fixed-telemetry stations in the Methow and Okanogan Tributaries was to identify the tributary selected by individual fish, and to establish entry time. Each fixed-telemetry site consisted of two antennas. Sites were placed downstream of known spawning grounds when possible.

Within the Okanogan River, most if not all spawning historically had occurred upstream of the town of Malott and so a station (Site 06) was established below this town; yet far enough up river that it did not pick up fish until they were committed to migrating upstream. A second receiver was placed in the Okanogan River Basin near the town of Riverside. This was done to monitor fish movement in the upper section of the Okanogan River as well as the Similkameen River-- areas that are known to contain major spawning habitat in the Okanogan Basin.

Fish have historically been observed spawning in the Methow basin over a long expanse of river that extends downstream, near the town of Pateros, at the confluence of the Methow and Columbia rivers. Consequently, a telemetry station (Site 07) was positioned at the lowermost spawning area to get the best coverage of fish entering the river. To avoid signal collision among tagged fish and undue loading of a receiver's memory, receivers were not located in areas where fish were expected to naturally congregate for extended periods of time.

1.6.5 Columbia River – monitoring stations

Five stations were set up on the Columbia River, three near the base of Chief Joseph Dam, a fourth near the Colville Tribal Trout Hatchery (trout hatchery), and the fifth below Wells Dam.

1.6.6 Chief Joseph Dam – monitoring stations

The three stations placed at the base of the Chief Joseph Dam (Figure 1) were set up to provide full coverage of fish movement in this area, with the intention of learning if the proposed hatchery ladder was suitably placed. These stations provided the following information:

- how tagged fish migrated upstream along the shoreline
- the extent tagged fish were detected in the area of the proposed hatchery ladder outfall
- generally, how tagged fish moved within the tailrace of the dam.

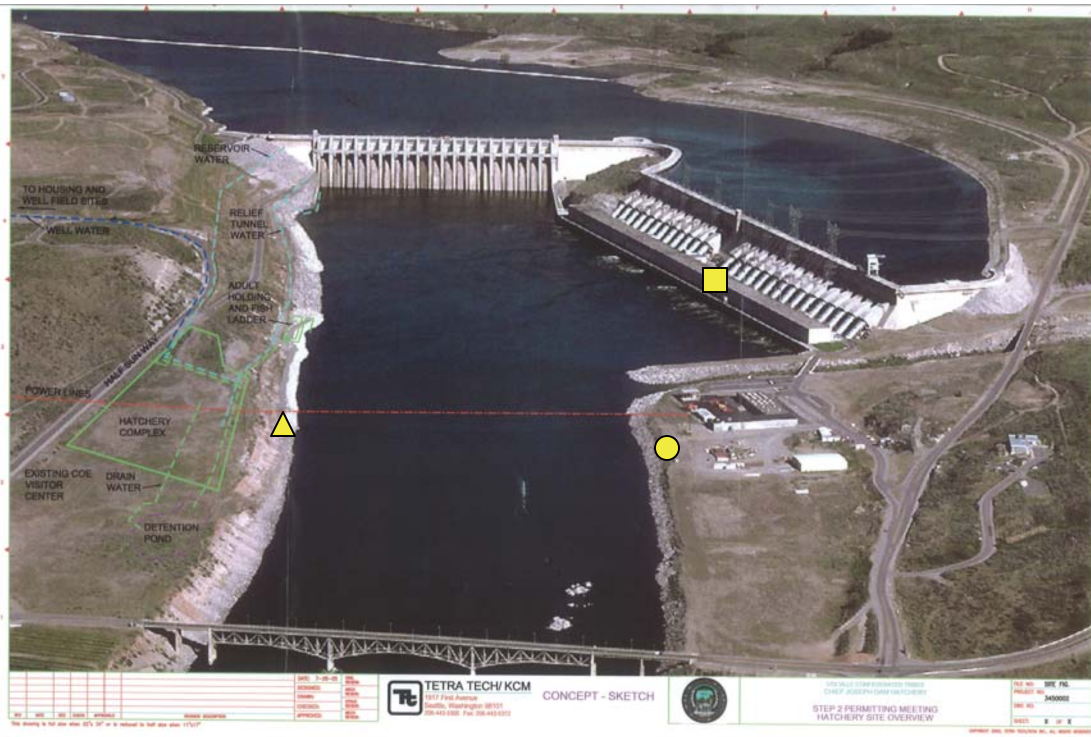

Figure 1. Photograph of the Chief Joseph Dam showing proposed hatchery site and ladder as well as location of radio telemetry fixed receiver Site 01 by a square, Site 02 by a circle, and Site 03 by a triangle. Photograph provided courtesy of Tetra Tech/ KCM.

1.6.6.1 __Powerhouse__

In order to monitor fish movement in the spill bay and in front of the powerhouse, a listening station (Site 01) was set up on the roof of the powerhouse (Figure 1, yellow square). Unlike the typical 40 degrees antenna placement, for this station three antennas were directed to fully cover the area below the Chief Joseph Dam and above the tailrace stations.

1.6.6.2 __Tailrace –left bank, south shore__

A fixed-telemetry station (Site 02) was installed with two antennas on top of the restricted access sign at Chief Joseph Dam, about 400 yards below the spillway gates. This station was located between Highway 17 and Foster Creek to monitor fish movements along the south shore (Figure 1, yellow circle).

1.6.6.3 __Tailrace – right bank, north shore__

The third station (Site 03) in the vicinity of Chief Joseph Dam used three antennas that were anchored to the top of the restricted access sign on the north bank of the river, directly across from Site 02. This station was located just below the proposed hatchery ladder outfall to provide information about how fish use the immediate vicinity (Figure 1, yellow triangle).

1.6.7 Colville Tribal Trout Hatchery

The trout hatchery station (Site 04) was set up with two antennas and was chosen because of the relative narrowness of the Columbia River in an area above the confluence of the Okanogan and Columbia Rivers. The narrowness enabled a potentially higher detection rate than the wider areas. This site enabled researchers to monitor fish passage in the mainstem Columbia just above the confluence of the Okanogan and Columbia rivers.

1.6.8 Wells Dam

To account for fish that may fall back below Wells Dam, a station (Site 08) was set up with two antennas about 800 meters below Wells Dam.

1.6.9 Aerial surveys

Aerial surveys were conducted throughout the study period. Surveys were conducted within the entire Okanogan basin, and included areas of known spawning. This included the Okanogan River between its confluence with the Columbia River and the town of Oroville (Zosel Dam), and the Similkameen River from its confluence to Enloe Dam located approximately 8 km upstream of the confluence. Researchers also monitored the Methow River from its confluence with the Columbia River to the town of Winthrop (3.2 km). A few surveys were also done over the Chewuch River, up to about 16 km from the confluence of the Chewuch and Methow Rivers, once a tagged fish moved into this Methow tributary. Aerial surveys were conducted using a fixed-wing aircraft with an "H" antenna mounted to each wing strut. The antennas were aimed downward from the wing and at an approximately 50 degree forward angle. To maximize fish detections, a single receiver simultaneously monitored the antennas. As the plane passed over strategic points on the route, time was recorded. The time that tags were recorded on the SRX was cross-referenced with the location of the plane to give a location for the fish.

1.6.10 Boat surveys

Boat surveys were conducted on a weekly basis during the study period, and occurred between the town of Brewster near the confluence of the Okanogan River and the Chief Joseph Dam tailrace. A 5.2 m Weldcraft aluminum boat equipped with a 65 horsepower Yamaha jet pump was used and researchers held a 3-element Yagi antenna to monitor fish movement between shorelines. During each survey, the tracking vessel traveled parallel to a shoreline approximately down the middle of the river to listen to both sides. For sections of the river that were wide, the listening area was divided into thirds to ensure accurate detections. Once a tagged fish was located, its general position was determined using triangulation techniques, and latitude and longitude were recorded. The accuracy of this method depended on a number of factors, primarily the depth of the tagged fish, but generally was accurate to within 30.5 m. As time permitted, fish locations were ascertained more precisely (< 7.6 m) by making several passes over the tag. Records of all fish detections were entered into a master database, which included latitude and longitude, date and time of detection, and the channel/code combination of the tracked fish. During a typical boat survey, once a fish was detected its position was not recorded again during that survey.

1.6.11 Other surveys

As time permitted, tagged fish were located during vehicle, raft, and foot surveys. These surveys were conducted more frequently after fish began to spawn and were used to locate live fish, tags in carcasses, and tags that had been removed from fish. Receivers used in mobile surveys were configured to allow for quick changes to the channel being monitored and to the gain. Although, receivers sometimes monitored channels on a six second interval, manual changes between channels allowed surveyors to listen to a channel continuously. This method typically provided a precise location of fish in the spawning grounds depending on the stream characteristics, accessibility, and the amount of time dedicated to home in on the exact location of a particular tag.

1.7 Data collection and evaluation

Prior to fieldwork, datasheets were created for fish that would be tagged and for information collected during the mobile surveys. The tagging datasheet included tag type, tag code, tag channel, date of tagging, ladder location, adipose fin clip, sex, and forklength. These datasheets were then entered into a database (Microsoft® Access™ v 9.006926; Microsoft Corp., Redmond, Washington) that was created by Dong Nguyen for this project.

The database structure enabled data to be entered efficiently and with minimal error. Data from the receivers was downloaded weekly using a laptop computer. Software (WinHost™ v 4.324; Lotek Wireless Inc., Newmarket, Ontario) was used to transfer data from the receiver to the computer as a text file. The text file was examined for obvious errors then imported directly into a primary data table in the database using an automated process. We maintained a field notebook recording detections of GPS location for tags detected during mobile surveys. The latitude and longitude corresponding to tag detections were then manually entered into the database.

Pre-set filters in the database program eliminated noise by comparing tag detection records from the receivers to the valid codes of released tags. Following this filtration process, queries were developed to address the study questions.

1.8 Data analysis

Peculiar or abnormal detections in the data table were identified using a variety of queries and through a tag-by-tag visual review of the data. False reads that were not removed by the built-in filters, detections of tags known to be removed from the river in a fishery, and detections of tags known or suspected to be in carcasses were addressed in the design of queries.

Based on the coordinates entered into the Access™ database, detections of tagged fish were assigned to a stream reach or "segment" (also referred to as detection area). Detection areas are described in Table 3 and illustrated in Figure 2. The first letter indicates the river and the following number indicates the reach starting at the lower part of the river and moving upward (Table 3, stream segment column). Detection areas were determined by the location of fixed receivers, stream characteristics, accessibility, and location and frequency of mobile surveys. Access™ queries were designed to use this common field between fixed site and mobile survey locations to group fish detections. Stream segments were also used to identify the uppermost destination of each fish. Simple mathematic functions were incorporated into the queries to determine passage times and migration patterns, and to sum tagged fish or individual detections by relevant criteria. The results of the queries were then exported to a spreadsheet program (Microsoft® Excel® v 9.0.6926; Microsoft Corp., Redmond, Washington) or to a GIS program

(ArcGIS™ v 9.1; Environmental Systems Research Institute, Inc., Redlands, California) for illustrating tag distribution.

Table 3. Description of stream segments used in analysis of radio telemetry data

River	Stream segment	Start	Rkm	End	Rkm	Considered spawning area in summary
Columbia Mainstem	C-01	Just below Wells Dam, Site 08	817.0	Confluence of Methow	831.0	No
	C-02	Confluence of Methow	831.0	Brewster Bridge (Hwy 173) and up Methow to Hwy 97 Bridge (Pateros)	841.0	No
	C-03	Brewster Bridge (HWY 173)	841.0	Colville Trout Hatchery (site 04) and including the mouth of Okanogan up to site 06	859.0	No
	C-04	Colville Trout Hatchery (site 04)	859.0	HWY 17 Bridge below Chief Joseph Dam	863.3	No
	C-05	HWY 17 Bridge	863.3	CJD (sites 1,2,and 3)	864.5	No
Methow River	M-01	HWY 97 Bridge (Pateros)	0.6	McFarland Creek confluence	29.9	Yes
	M-02	McFarland Creek confluence	29.9	Twisp River confluence	67.3	Yes
	M-03	Twisp River confluence	67.3	Chewuch River confluence (Winthrop)	83.8	Yes
Chewuch River	H-01	Chewuch River confluence with Methow River	83.8	Approximately 16 km above confluence with Methow River	16.0	Yes, considered part of Methow (M-03) in summary
Okanogan River	O-01	Fixed Site 06	10.7	Omak Avenue Bridge (Omak)	49.9	No
	O-02	Omak Avenue Bridge (Omak)	49.9	Similkameen Confluence with Okanogan	126.5	Yes
	O-03	Similkameen confluence	126.5	Zosel Dam.	129.3	Yes
Okanogan side channel along east side of Driscoll Island	K-01	South end of Driscoll Island	120.3	North end of Driscoll Island	127.2	Yes, considered part of Okanogan (O-03) in summary
Similkameen River	S-01	Similkameen confluence with Okanogan	126.5	12th Avenue Bridge (Oroville).	2.8	Yes
	S-02	12th Avenue Bridge (Oroville)	2.8	Railroad bridge below Enloe Dam.	5.4	Yes
	S-03	Railroad bridge below Enloe Dam	5.4	Enloe Dam	8.8	Yes (though likely not used)

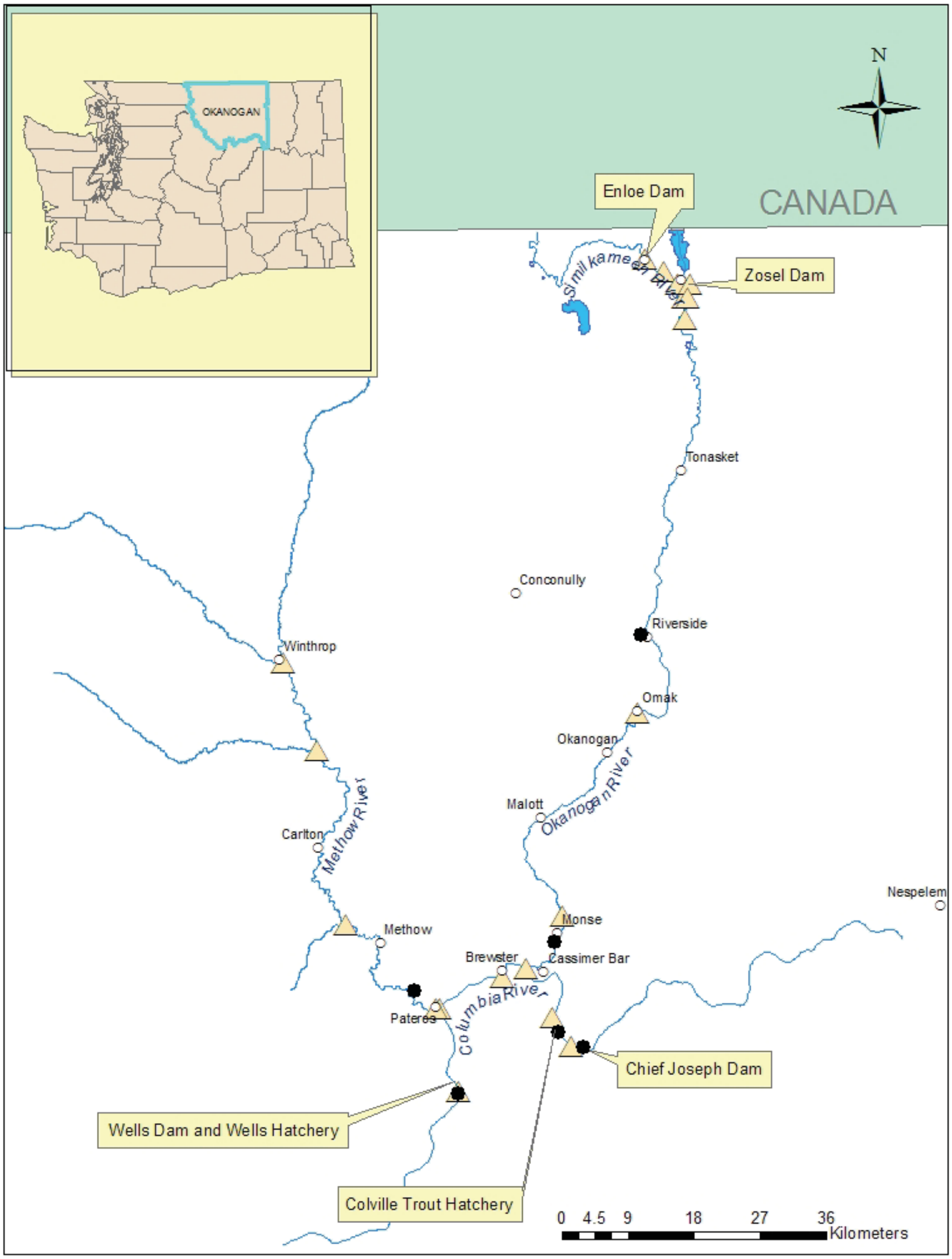

Figure 2. Study area for Chinook migration and movement study above Wells Dam. Clear circles represent towns, dark circles show fixed receiver sites, and triangles depict mobile receiver segments.

2. Results

2.1 Radio tagging fieldwork

Tagging began on 5 July 2005, and the last fish was tagged on 9 November 2005. A total of 292 predominantly wild Chinook received radio tags and were released. One fish died soon after tagging and the carcass was recovered at the Starr Boat Launch release site. In total, 291 fish were tagged and lived immediately (99.66%) following release (Table 4). Although we planned to only tag wild fish (visually distinguished from hatchery fish by the presence of an adipose fin), hatchery fish were tagged when there were difficulties meeting the tagging goal for a two-week or greater time period. Too few Chinook passed Wells Dam the last few weeks of the season, preventing the application of all 300 radio tags. Limitations to the tagging operation included working around Endangered Species Act requirements that the trap be operated only three days per week (generally Monday through Wednesday) and waiting until weekly local hatchery broodstock collections from the traps were met.

Table 4. Number of radio tagged fish released by date for Chinook migration and movement study.

Study week	Dates	Tag goal	Number released
1	July 3 – 9	20	18
2	July 10 – 16	20	33
3	July 17 – 23	25	25
4	July 24 – 30	25	22
5	July 31 – August 6	20	20
6	August 7 – 13	15	17
7	August 14 – 20	15	29
8	August 21 – 27	15	15
9	August 28 – September 3	15	12
10	September 4 – 10	15	19
11	September 11- 17	10	11
12	September 18 – 24	10	16
13	September 25 – October 1	10	12
14	October 2 – 8	10	10
15	October 9 – 15	10	9
16	October 16 – 22	10	12
17	October 23 – 29	10	3
18	October 31- November 5	10	0
19	November 6 – 12	10	8
All	Total	300	291

2.1.1. Comparison of tagged fish with total adult Chinook migration and temperature patterns

The peak of adult Chinook migration over Well's Dam was on 9 July with 1,779 Chinook (Figure 3). The water temperature peaked at Well's Dam on 18 August and 19 August then again on 28 August through 8 September at 19.4 degrees Celsius. For clarity, the area within the Figure 3 box is expanded in Figure 4. The spring, summer, and fall Chinook run displays a bimodal curve with the spring Chinook run extending the length of the first curve and the summer/fall Chinook run curve beginning the last week of June or first week of July and extending into August (Swan et al., 1994; Stuehrenberg et al., 1995; and Alexander et al., 1998).

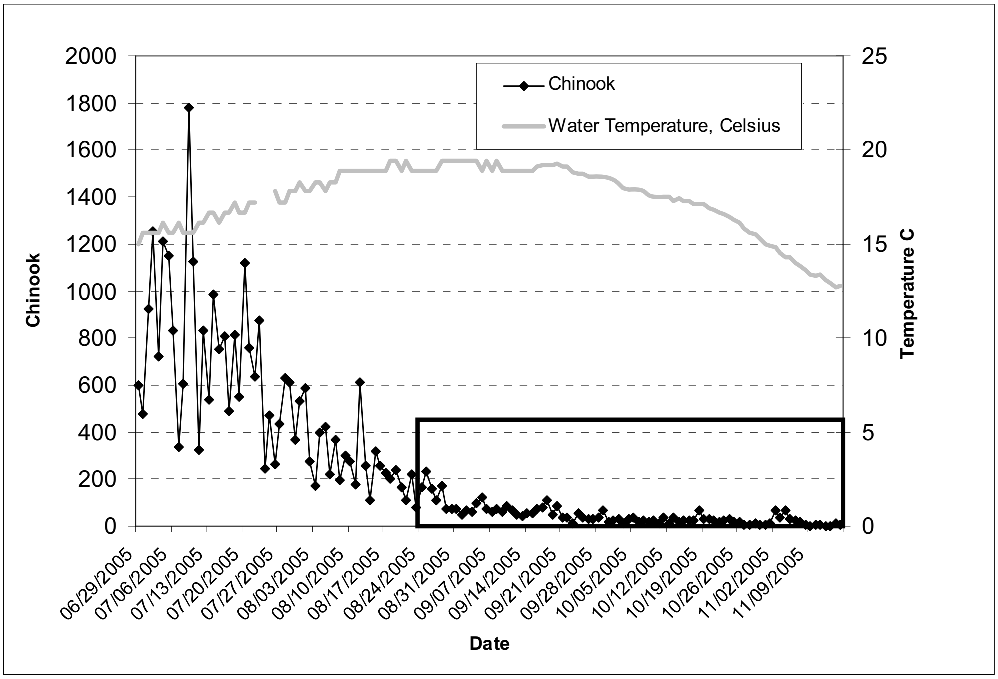

Figure 3. The tail end of spring Chinook and entire run of summer/fall Chinook passage at Well's Dam compared with water temperature. To view boxed section more closely, see following figure.

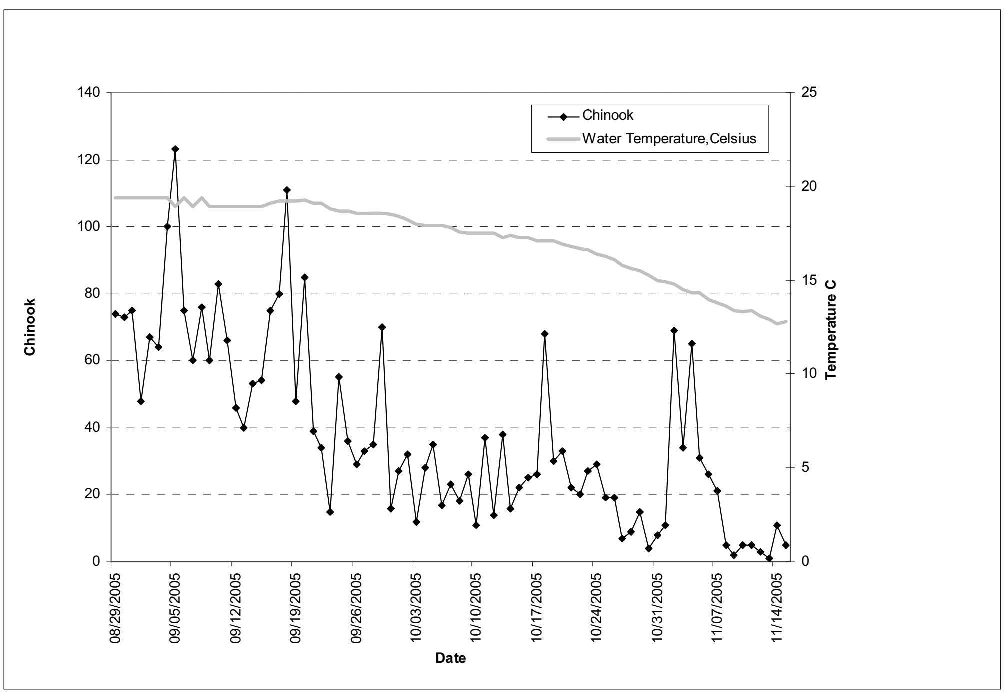

Figure 4. Boxed area from previous figure, showing detail of the late Summer/Fall Chinook passage through Wells Dam between August 29 and November 15.

The cumulative number of Chinook passing Wells Dam totaled 34,075 at the end of the twentieth study week. The cumulative number of Chinook tagged compared to the cumulative number passing Wells Dam is illustrated in Figure 5. Over the entire season, the number of returning Chinook represented by each of the 291 tags was 117. On a weekly basis, the number of fish tagged was not the same proportion to the number of fish passing Wells Dam. The proportion of fish passed per fish tagged ranges from 368 to 8 and is generally higher for weeks early in the season when the number of Chinook passing Wells Dam was greater and lower for weeks later in the season when Chinook passage declined. Consequently, a fish tagged in October that ended up in the Columbia may represent 15-20 fish whereas a fish tagged in July that went into the Okanogan River may represent 350 fish.

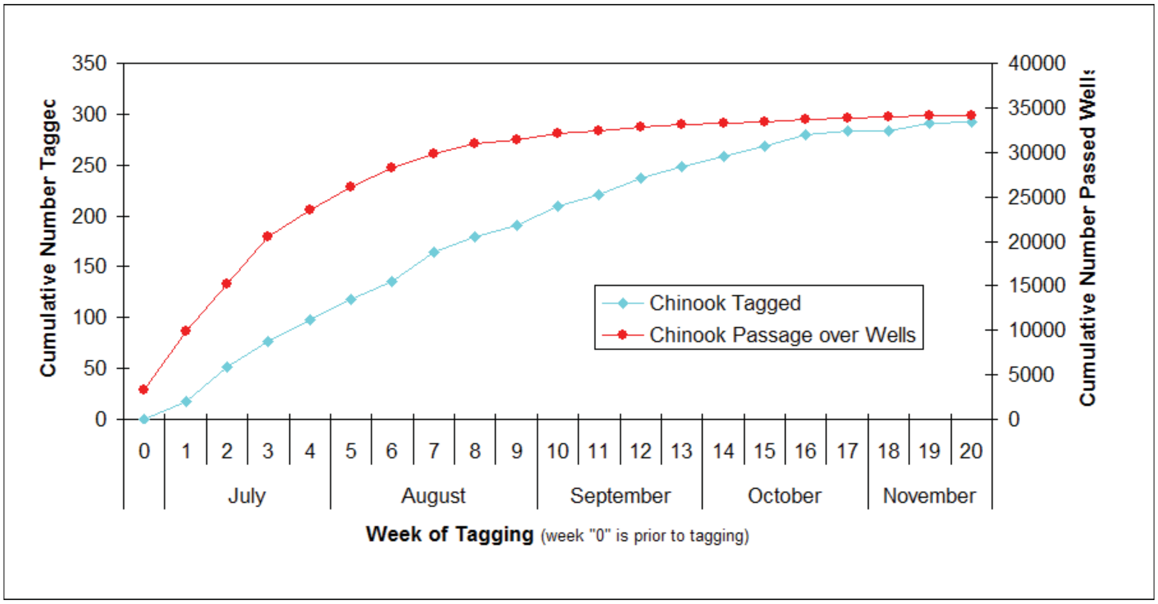

Figure 5. Cumulative number Chinook tagged and cumulative number of Chinook that passed Wells Dam in 2006.

The percentage of fish that passed Wells Dam weekly that received radio tags ranged from 0% to 16.9%. We did not tag any fish during weeks 18 and 20 because none moved through the east ladder during the days the trap was open. The west ladder was shut down weeks 18 through 20, making it more difficult to capture and tag fish. During week 19, a total of 65 fish passed the dam and we tagged 11 of them, giving us the highest number tagged by number that passed the dam (16.9%). As explained above in the Methods Section, the tagging schedule was arranged so that more fish would be tagged at the end of the run than at the beginning, because it was expected that more late arriving fish than early arriving fish would move into the Okanogan Basin as a result of high Okanogan River temperatures. As a result, the cumulative tagging in Figure 5 is depressed compared to the cumulative run size of Chinook over Wells Dam.

2.1.2. Fixed and mobile tracking stations

As planned, eight fixed sites were installed throughout the study area. Seven of these were set up and began receiving signals as of 6 July. The eighth fixed station, located in the town of Riverside, was not set up until 22 July because of a delay in equipment arrival. This site was chosen to be set up last because local biologists expected that it would not receive fish until the warm water at the mouth of the Okanogan River dissipated much later in the season. Aerial surveys occurred from 14 July to 27 October and boat surveys occurred from 8 July to 28 November. Monitoring by fixed receiver stations and vehicle surveys continued until 6 December 2005, when observations indicated that no tagged fish were alive.

Aerial surveys covered the mainstem Columbia between the Wells and Chief Joseph Dams as well as the Methow, Okanogan and Similkameen Rivers and selected tributaries of each. The Similkameen River surveys typically extended to Enloe Dam as well as Zosel Dam on the Okanogan River. Surveys occasionally covered a greater distance, extending into Canada, although no detections nor redds were observed. In addition to the two aerial surveys that extended into Canada, there was one boat survey of Osoyoos Lake and occasional vehicle surveys.

2.1.3. Download, detection, and recovery of radio tags

Receivers were typically downloaded every week. After false reads were removed, the telemetry database held 920,203 records representing over 2.1 million individual tag detections. Of the 291 tagged fish we released, 110 (37.80%) were either returned by fishers or recovered during spawning ground and mobile surveys. Including the tags recovered, 280 (Table 5, 96.22%) were detected by the fixed site receivers or during mobile surveys. Recovered tags were recorded as a mobile detection only when the recovery location was known.

Table 5. Number of tags released and later recovered or detected by fixed and mobile receivers.

Location	Number telemetry tags released	Number recovered	Number detected at fixed stations	Number detected or recovered (fixed and mobile)
Wells Dam	291	110	268	280

2.2 Evaluating potential population differences using biological data

To learn whether there were biological differences that would indicate distinct populations of Chinook, we noted which ladder fish passed through to see if this was related to their final destination. Because some hatchery fish were tagged, we also determined whether hatchery and natural origin Chinook used different ladders when they passed over Wells Dam. In addition, fork length and age were considered. Genetics is a standard means of distinguishing adaptations within and among populations so we also collected DNA.

2.2.1. Passage location

Fish from both ladders were tagged, which enabled us to see if Chinook caught in each ladder differed from one another (Table 6). We evaluated which side of the river (east or west ladder) fish passed through and their uppermost detection location using a chi square test for homogeneity and did not find a significant difference (Table 7, P=0.2668). This result indicates there is no difference between Chinook passage location at Wells Dam and destination.

Table 6. Summary of tags released, recovered and detected by fixed and mobile receivers.

Location	Number telemetry tags released	Number recovered	Number detected at fixed stations	Number detected or recovered (fixed and mobile)
East Ladder Wells	161	65	142	152
West Ladder Wells	130	45	126	128
Wells Dam (both Ladders)	291	110	268	280

Table 7. Uppermost detection (using fixed and mobile receivers) of Chinook by tag and release location.

River	East Ladder Wells	West Ladder Wells	Total
Columbia	69	48	117
Methow	16	19	35
Okanogan	34	24	58
Similkameen	33	37	70
All	152	128	280

2.2.2. Origin (hatchery or wild) differences

We also evaluated fish origin (hatchery or wild) and their uppermost detection location using a chi square test for homogeneity. Here we found a significant difference, with more than the expected number of Similkameen River fish of wild origin (Table 8, P=0.0312).

Table 8. Uppermost detection (using fixed and mobile receivers) of Chinook by adipose fin clip present or absent.

River	Hatchery	Wild	Total
Columbia	12	105	117
Methow	2	33	35
Okanogan	7	51	58
Similkameen	0	70	70
All	21	259	280

2.2.3. Size differences

Fork length was measured on 288 of the 291 Chinook that were given radio tags. Because we did not radio tag small fish, this information is not expected to reflect the size of adult Chinook that passed through Wells Dam. We evaluated fork length differences for the uppermost detection location of radio tagged fish and did not see differences (Table 9). The range was smaller for fish captured at the east ladder (Table 10) but the average fork length was not significantly different between ladders. The fork length of radio and jaw tagged fish was also broken down by study week (Table 11), and no differences were observed.

Table 9. Fork length by uppermost detection for radio tagged fish. The group "All radio tagged fish" includes 11 tagged fish that were never detected

River	Average Forklength	Measured Fish	Tagged Fish	Range	S.E.
Columbia	85.1	117	117	68-101	7.76
Methow	86.9	35	35	73-104.5	6.32
Okanogan	83.6	56	58	69.5-101.5	7.00
Similkameen	85.9	69	70	72.5-101.5	5.45
All of above	85.2	277	280	68-104.5	6.95
All radio tagged fish	85.3	288	291	67-107	7.10

Table 10. Fork length by Wells Dam passage location, East Ladder or West Ladder. Data includes both radio and jaw tagged fish.

Passage Location	Average Fork length	Measured Fish	Tagged Fish	Range	S.E.
East Ladder	80.4	669	674	30.5-107	10.28
West Ladder	81.8	335	336	51.5-114.5	10.10
Total	80.9	1004	1010	30.5-114.5	10.24

Table 11. Fork length of Chinook passing through Wells Dam that were radio and jaw tagged by week. Data that does not apply is noted by "na" for "not applicable".

Study Week	Average Forklength	Number of Measured Fish	Detected Fish	Range	S.E.
1	84.9	69	70	65.5-100.5	7.61
2	82.7	98	98	53-114.5	10.14
3	82.8	153	153	65.5-100.5	7.54
4	81.8	70	70	61-109	8.08
5	80.4	74	77	43-97.5	11.07
6	79.0	84	84	54.5-95.5	9.66
7	81.8	119	119	56.5-107	9.16
8	84.1	61	62	64.5-102.5	8.49
9	83.7	31	31	52-97	9.82
10	79.6	37	47	52-107	13.74
11	74.2	26	26	51.5-98	11.93
12	76.1	49	49	52.5-94	10.88
13	74.3	23	23	55.5-100.5	10.77
14	71.7	17	17	30.5-90	13.06
15	73.6	16	17	46.5-97	13.70
16	78.6	53	53	44.5-112.5	12.46
17	79.8	3	3	70-85	8.52
18	na	na	na	na	na
19	80.4	11	11	62.5-91	8.64

2.2.4. Scale analysis

When possible, scales were collected from Chinook that were chosen to receive radio telemetry tags. Not every fish where scales were collected received a telemetry tag and further, scales that were collected were not always legible for aging. John Sneva of WDFW read the scales. Of the scales that were collected and read, the data was evaluated by month of capture at Wells Dam, by whether the analysis determined the fish was wild, hatchery, or reservoir reared, and by age. As we expected, nearly all the fish were wild both overall and by month (Figure 6). Further, all fish designated as wild reared in a river environment. Fish that were reservoir reared could have come from natural or hatchery spawned adults. Reservoir rearing can refer to fish that are released from a hatchery as fry; for example, fish that were released from the WDFW Turtle

Rock facility, and rear in a lake (reservoir) environment such as the mainstem Columbia River. Reservoir rearing can also refer to wild fish that reared in the mainstem Columbia River. Consequently, the reservoir reared group cannot be assigned to parentage (hatchery or wild) using scale analysis. The wild reared salmon were typically four year old fish (Figure 7), while the hatchery and reservoir reared salmon were typically five year old fish (Figure 8 and Figure 9).

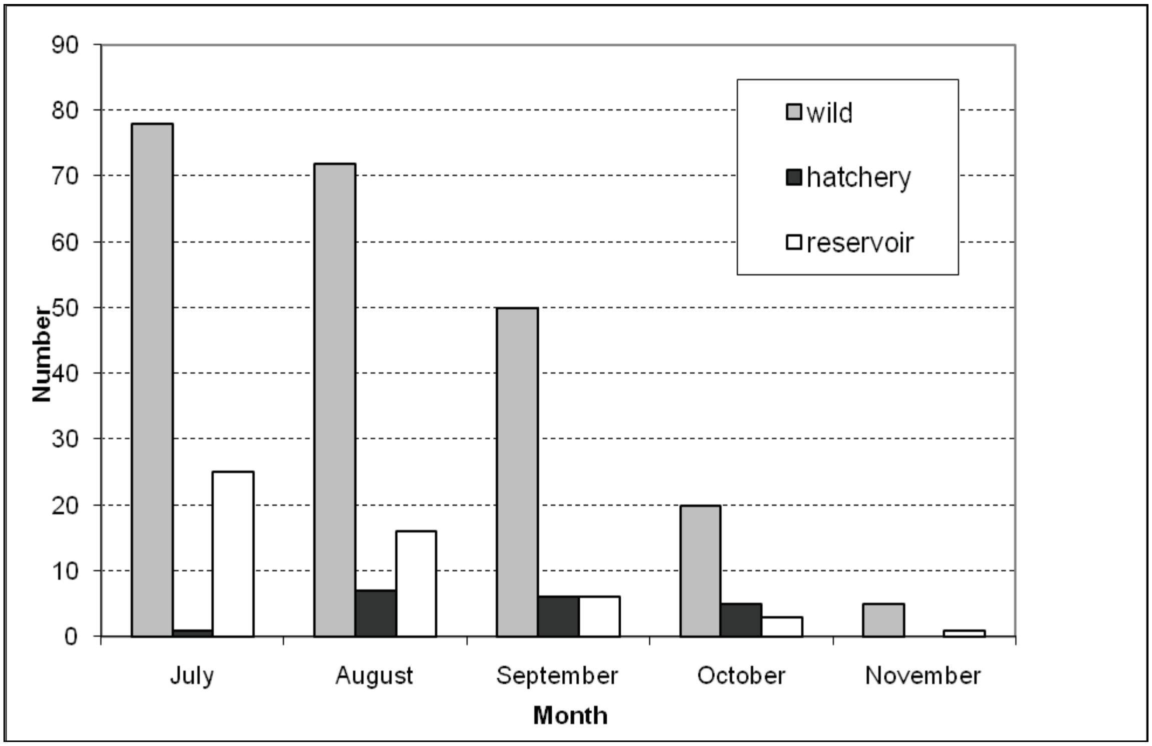

Figure 6. Distribution of Chinook salmon scale samples by rearing (wild, hatchery, and reservoir) by count and passage month through Wells Dam fish ladders.

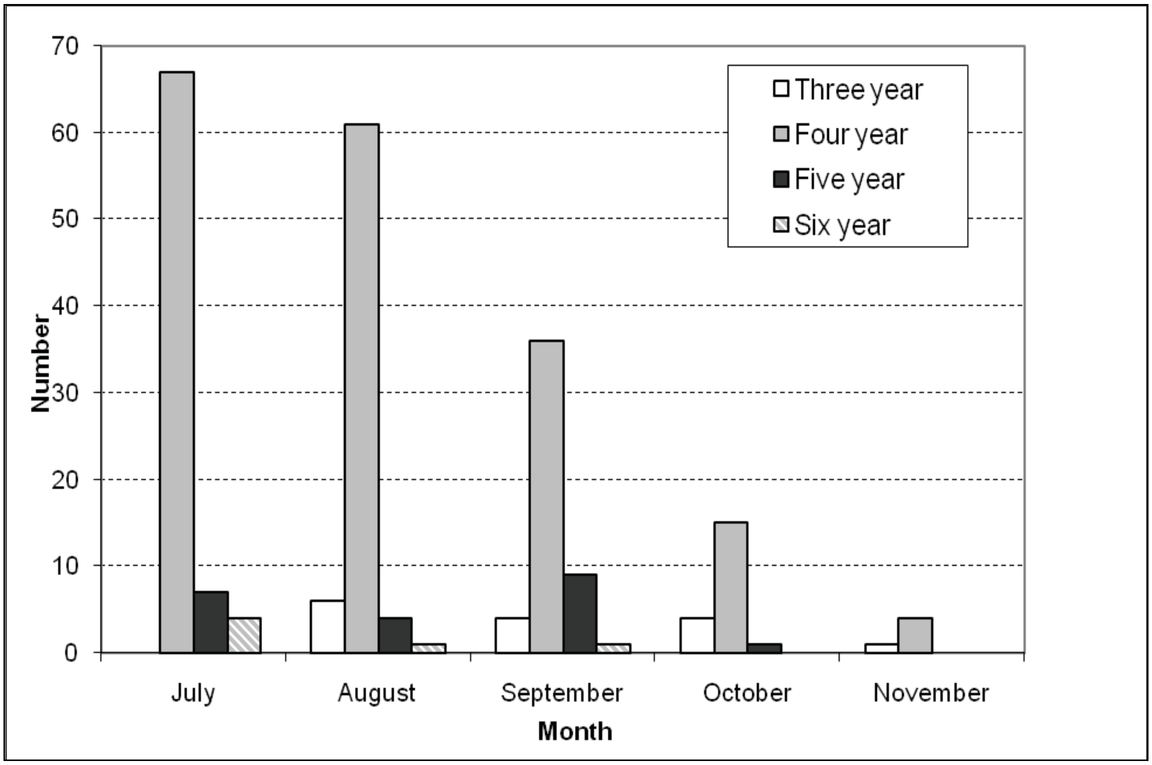

Figure 7. Distribution of scales that were determined to be wild salmon by count, age, and passage month through Wells Dam fish ladders.

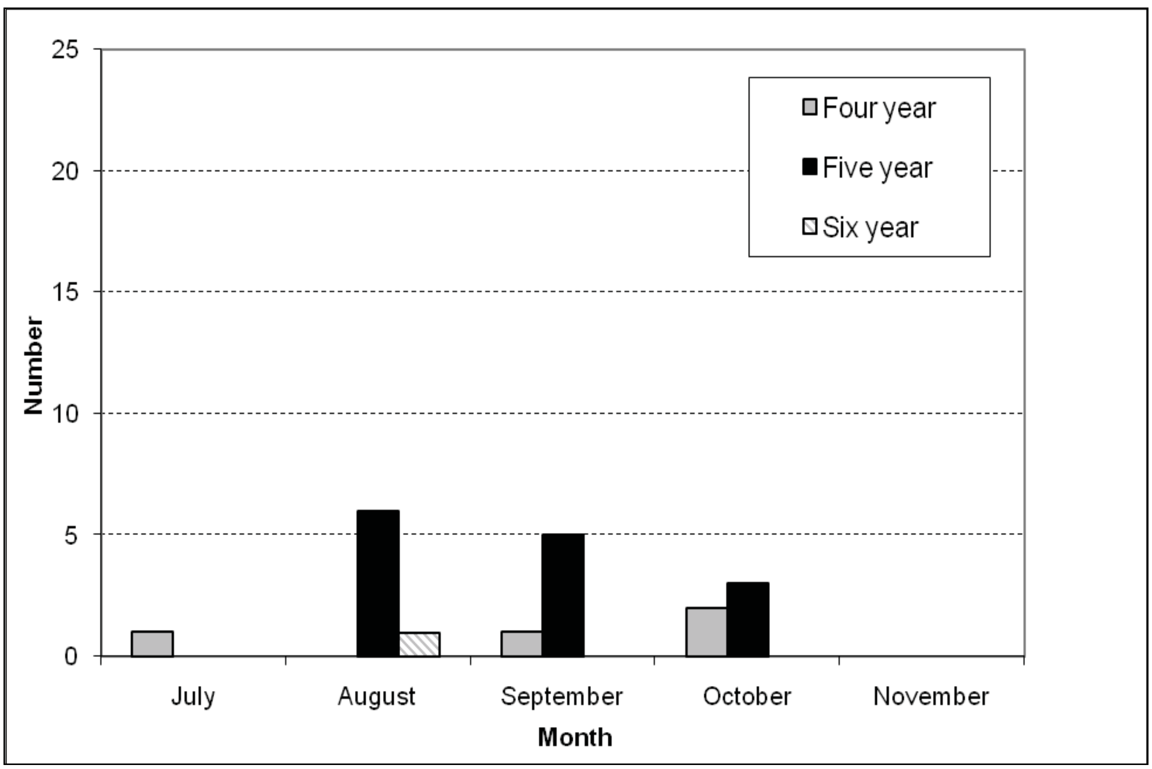

Figure 8. Distribution of scales that were determined to be hatchery reared by count, age, and passage month through Wells Dam fish ladders.

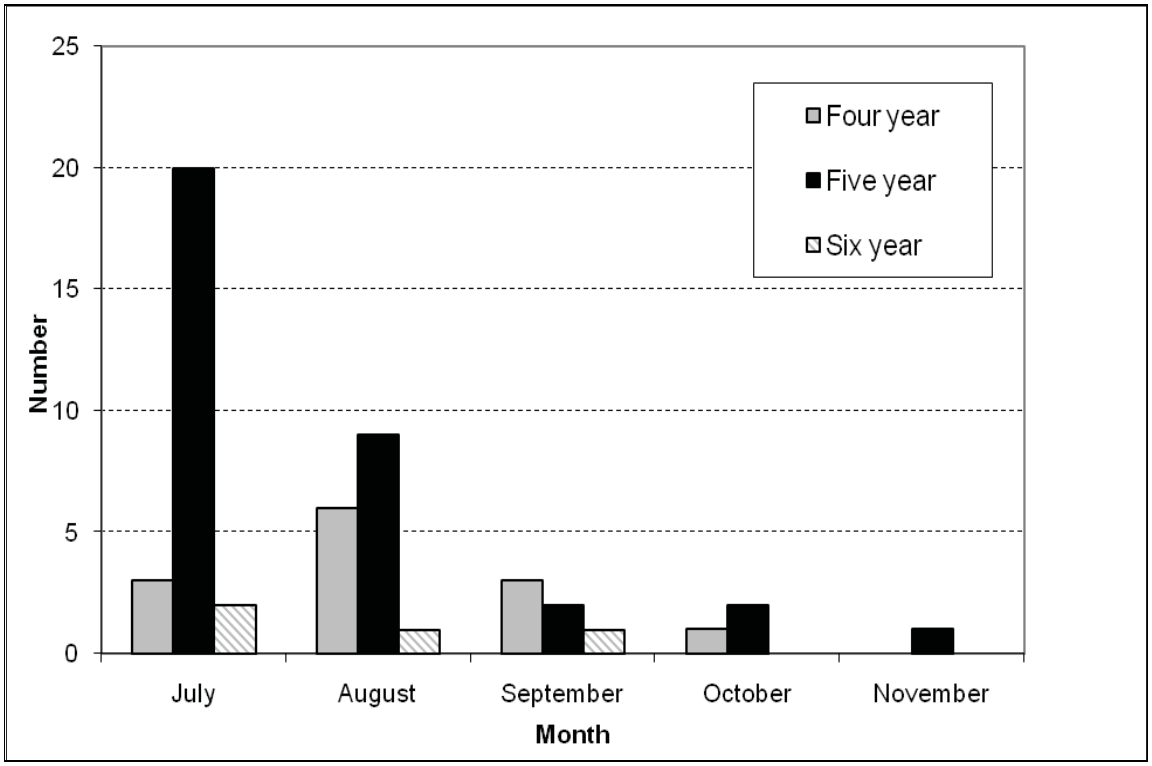

Figure 9. Distribution of scales that were determined to be reservoir reared by count, age, and passage month through Wells Dam fish ladders.

2.2.5. Jaw tag recovery

Chinook that were jaw tagged consisted of fish that were trapped after the weekly radio tagging goal was met, hatchery fish (that were not radio tagged), and fish that were too small to receive a radio tag. In total, 672 hatchery and wild Chinook were given jaw tags from 6 July, 2005, through 9 November, 2005. Of the 672 fish, 482 (71.73%) were tagged at the east ladder of Wells Dam and released back into the ladder and 190 (28.27%) were tagged at the west ladder of the dam, transported to Starr boat launch, and released. The breakdown by hatchery and wild fish was about even, with 292 hatchery (ad clipped) fish (43.45%) and 380 wild (unclipped) fish (56.55%).

Technicians and biologists with much experience at surveying streams in this area observed that jaw tags appeared to be missing from fish and that pieces of the mouth where the jaw tag would have been attached were missing on carcasses. Further, not all stream surveyors looked for jaw tags when the stream surveys first began. These reasons could explain why more jaw tag recoveries occurred for harvested fish (Table 12). A chi square test was highly significant (P=0.005) for recoveries by date (Table 13). Similar to the radio tag results, most jaw tag recoveries occurred in the Columbia River (38), followed by the Okanogan system (19; Table

14). Most jaw tags were recovered well after spawning occurred, so these data do not provide information about passage time relative to location or time of spawning.

Table 12. Number of jaw tags recovered by type.

Recovery Type	Number
Tribal	25
Spawning ground	7
Sport	26
Total	58

Table 13. Number of jaw tagged Chinook released by date.

Release Dates	Number Released	Recovered	% Recovered
July 6 – 27	278	7	2.5%
Aug 1 - Sept 8	287	37	12.9%
Sept 13 – 29	50	5	10.0%
Oct 3 - Nov 9	57	9	15.8%
Total	672	58	8.6%

Table 14. Number of jaw tags recovered by basin and area. When the location of the recovered tag was not specified within a river basin, the location is listed as "general."

Recovery Basin	Recovery Area	Number
Columbia	Chief Joe Dam	34
	General	3
	Wells	1
	Total	38
Okanogan	General	1
	Mouth	9
	Upper section	1
	Similkameen	8
	Total	19
Methow	General	1
All	Grand Total	58

2.2.6. Compare the results for wild and hatchery fish

An examination of differences in movement patterns for individual hatchery fish compared to wild fish did not show any differences. Further, few hatchery fish (21; 7.22%) were radio tagged and so a full comparison was not done. Instead, data obtained from radio tagged hatchery fish were added to the information collected on wild fish for analysis.

2.3 Relationship between passage time through the Wells Dam relative to destination and spawning time

Objective 1. Identifying the locations and arrival times of fish that spawn in the upper portion of the Columbia Cascade Province relative to their passage time at Wells Dam.

2.3.1. Passage time through Wells Dam relative to destination

Chinook destination was evaluated by using the fixed and mobile receivers to evaluate the uppermost location of each radio tagged fish. The uppermost destination was defined as the furthest section of the final Columbia tributary that fish entered prior to when spawning activity began. Spawning activity was judged by visual observation of redd digging and other mating behaviors during mobile surveys. To evaluate the uppermost destination relative to passage time through Wells Dam, detected fish were first evaluated by tributary: Methow, Okanogan, Similkameen, or mainstem for fish that did not move into a Columbia tributary (Figure 10). A chi square test of homogeneity showed that Wells Dam passage timing relative to uppermost destination was highly significant ($P<0.001$). For Similkameen-bound fish, there was a clear pattern to these results. Many more fish showed up than were expected in July and in August. However, in the following months, many fewer fish than expected arrived (Figure 10). The same pattern occurred for fish whose uppermost destination was the Okanogan River (includes the upper and lower sections). Although no fish that passed the dam in November ended up in the Okanogan, this could be an artifact of the small number of fish tagged that month. Chinook that did not migrate into tributaries but remained in the mainstem Columbia were fewer than expected for fish that passed Wells in July and more than expected for fish that passed Wells during the months of August, September, October, and November. Chinook whose uppermost destination was the Methow River were much fewer than expected for fish that passed Wells during the month of August; for the months of July, September, and October there were a few more fish than expected.

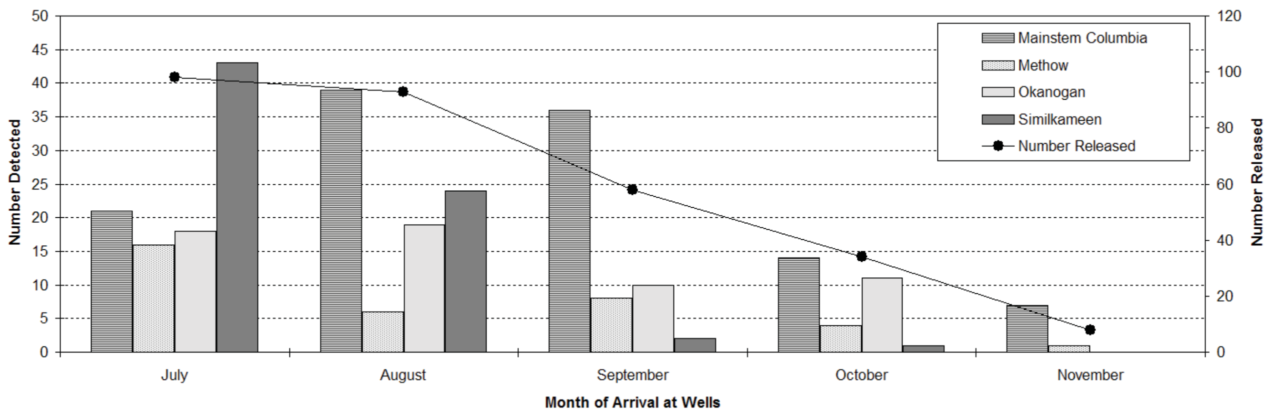

Figure 10. Number of fish detected in each stream (using fixed and mobile receivers) by month of arrival at Wells Dam, using mobile receiver data to separate the Okanogan and Similkameen Rivers.

Next, the 128 fish whose uppermost destination was the Okanogan River Basin were sorted by lower and upper sections where the lower Okanogan is defined as the reach between the confluence of the Okanogan River with the Columbia River and the town of Omak, and the upper Okanogan is defined as the reach extending from Omak upward to Zosel Dam. The Similkameen River section is the reach that extends from the confluence of the Okanogan and Similkameen Rivers to Enloe Dam. The chi square test of homogeneity showed the result to be highly significant (Figure 11; $P<0.001$), with Chinook that passed through Wells Dam in the month of July more likely to migrate to the Similkameen River and Chinook that passed through Wells Dam in September and October more likely to end up in the lower Okanogan River.

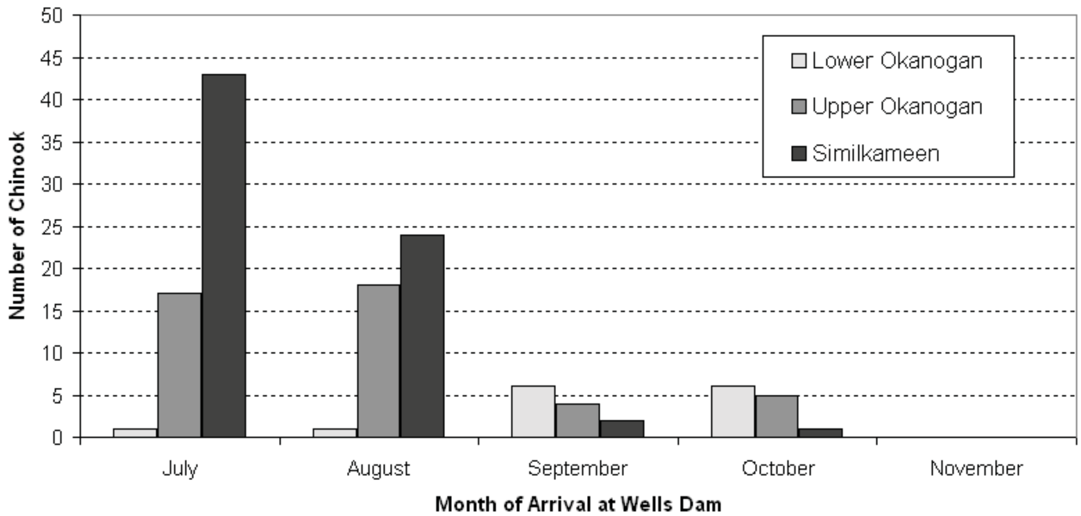

Figure 11. Number of Chinook with uppermost destination (using fixed and mobile receivers) in the Okanogan Basin relative to month of passage at Wells Dam.

2.3.2. Arrival time at spawning ground relative to passage time at Wells Dam

Arrival time at the spawning ground relative to passage time at Wells Dam was based on detections of tagged fish that were observed in the immediate vicinity of redds. On 21 and 22 September 2005, surveys were conducted and both tagged fish detections and un-tagged fish observations suggested that Chinook were still holding and not spawning. Most spawning seemed to occur between 6 October, 2005 and 12 October, 2005. During the 25 October 2005 survey, large numbers of carcasses were observed floating downstream. Few spawning observations were made on or after 25 October, 2005. Fish that were tagged at the end of our study did not follow the same pattern as the earlier arriving fish; a large proportion no longer moved to the base of the Chief Joseph Dam, though some remained in the mainstem Columbia. The average number of days between release at Starr Boat Launch during the month of July and suspected spawning date based on field observations was 87 days (Table 15).

Table 15. Observation of fish on spawning grounds by month that fish passed Wells Dam.

Tag Month	No. Tagged	No. from this month that were detected among redds	Observation percent	Average days between release and observation
July	98	32	32.65%	87
August	93	28	30.11%	59
September	58	5	8.62%	30
October	35	1	2.86%	8
November	8	1	12.50%	7

We observed that fish used the upper Okanogan River and Similkameen River heavily for spawning (Figure 12). Of the three tributaries, Similkameen fish on average took the longest number of days to travel to the spawning grounds (Figure 13). The passage time for Similkameen fish may be artificially inflated because the first survey of the Similkameen River did not occur until 16 September; however, because this trend exists for each month that fish were tagged at Wells Dam, it is unlikely to be an artifact.

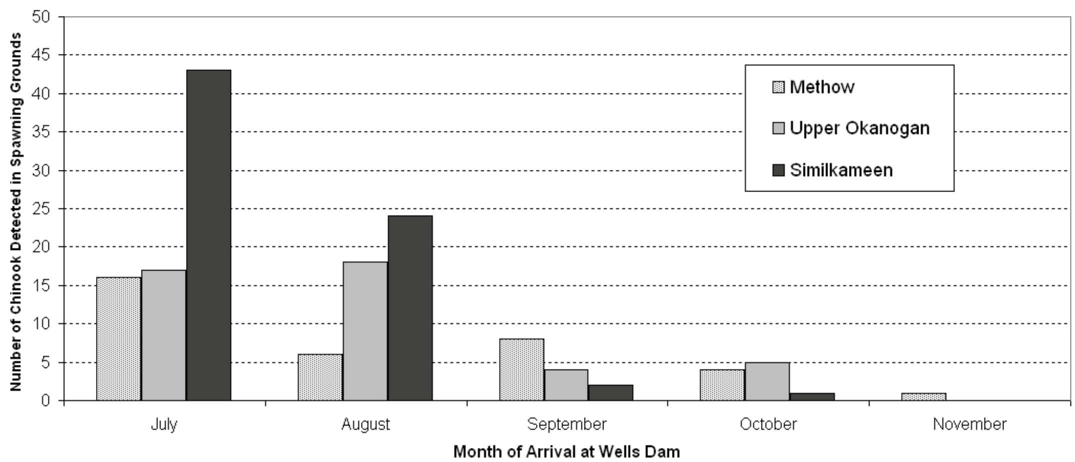

Figure 12. Number of fish detected on spawning grounds (using detections from fixed and mobile receivers) by month of passage through Wells Dam. This data is based on spawning grounds as identified by spawning surveyors as well as areas where we observed spawning occurring.

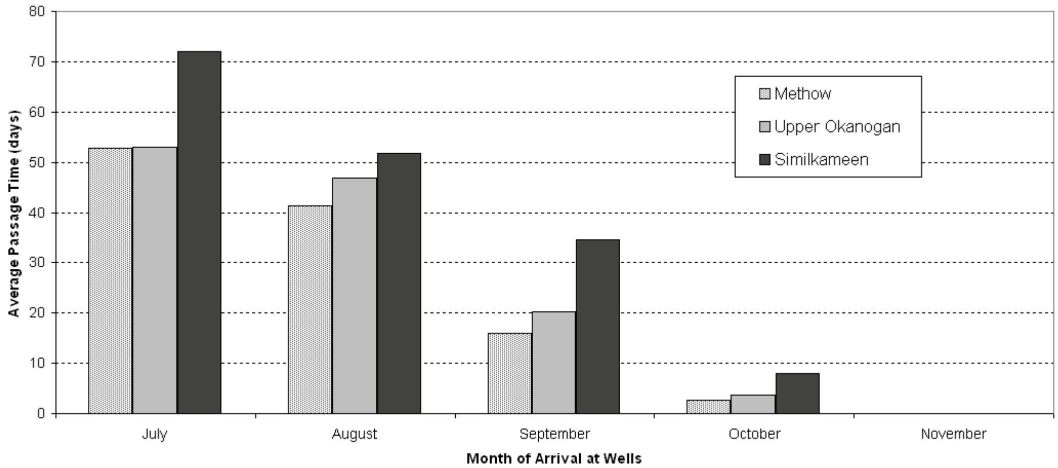

Figure 13. Average number of days to reach spawning grounds (using detections from fixed and mobile receivers) by month of passage through Wells Dam.

Although the range was broad for both spawning location and spawning ground arrival date relative to the date of passage at Wells Dam, there were correlations (Figure 14 and Figure 15). Both spawning location and spawning ground arrival date are related to passage date at Wells Dam. The coefficient of determination between arrival at Wells Dam and first detection in the Okanogan River is 0.3090 (r=-0.556; Figure 14) while the coefficient of determination between time of arrival at Wells Dam and arrival date on the spawning grounds is higher, 0.4772 (r=0.691; Figure 15). A t-test (Zar, 1999) showed these results to be significant (($P(|t_{126}|=7.507 <0.05)$ and ($P(|t_{126}|=10.725) <0.05$), respectively).

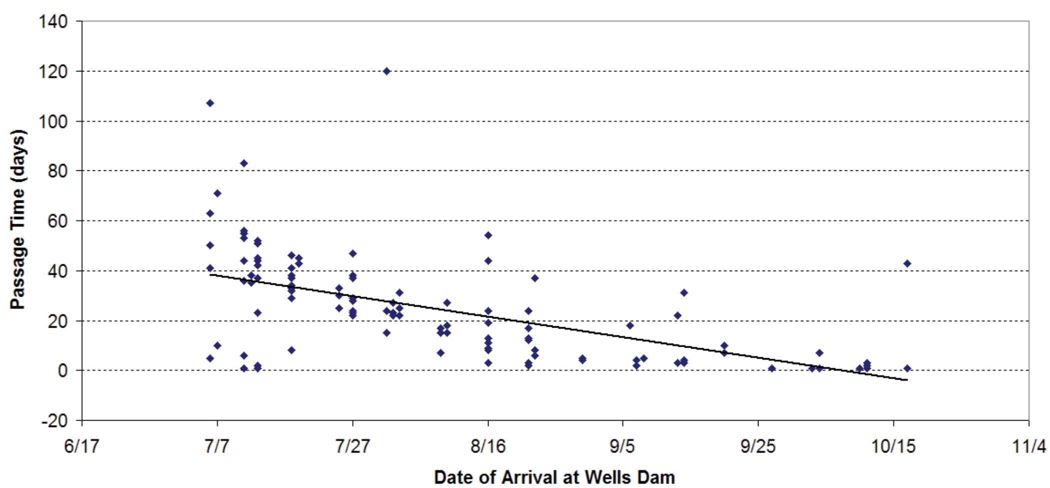

Figure 14. Date of Chinook arrival at Wells Dam compared to passage time in days with first detection at or above the fixed receiver in the lower Okanogan River (Site 06) using fixed and mobile receivers.

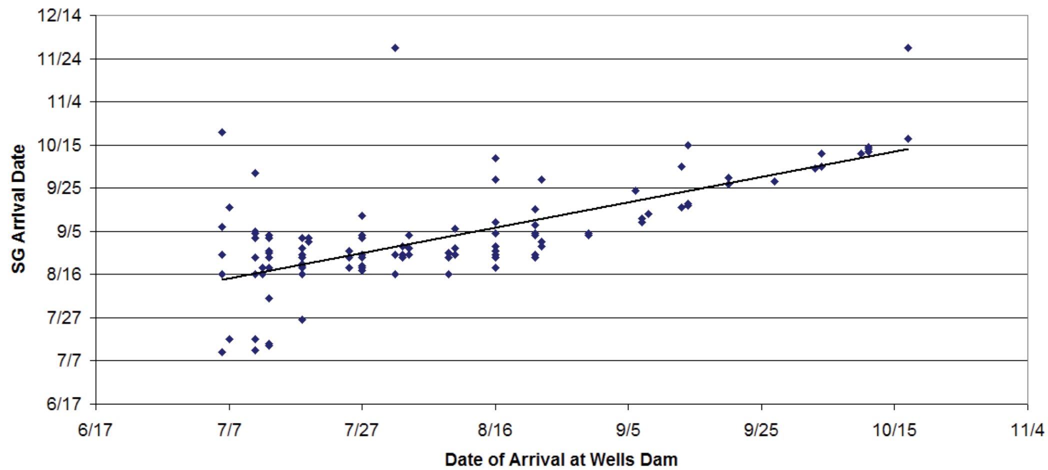

Figure 15. Date of Chinook arrival at Wells Dam compared to arrival date on spawning grounds (SG) above the lower Okanogan River (Site 06) using fixed and mobile receivers.

2.4 Evaluation of proposed hatchery ladder

Objective 2. Describing the movement patterns of fish that migrate to Chief Joseph Dam to learn if they prefer particular areas and determine their final destinations.

2.4.1. Location suitability to draw adults into the hatchery

The ladder location is planned to be on the right bank of the Columbia River near the base of Chief Joseph Dam. A total of 157 radio tagged fish were detected near the base of the dam and of those fish, 138 (87.90%) were detected by receivers on both sides of the river. To learn if there was a side that the fish preferred, we looked at first detection location to see if the fish were more likely to swim into the area from one side of the river. Most fish (70.06%) were first detected on the right bank. However, once in the area, most fish moved between both banks of the river (Table 16). The final detections of radio tagged fish were nearly evenly distributed, 84 (53.5%) on the right bank and 73 (46.5%) on the left bank.

Table 16. Location preferences of fish that traveled to the base of Chief Joseph Dam using fixed receivers.

First detected on right bank (Site 03)	110	Also at 02 on same day	58
		Also at 02 at any time	95
		Only detected at 03	15
First detected on left bank (Site 02)	47	Also at 03 on same day	36
		Also at 03 at any time	43
		Only detected at 02	4
Total	157	detected at both sites	138

Another way to assess whether the ladder is suitably placed is to evaluate which side of the river fish were detected for more days. More fish (91) were detected for more days on the right bank than on the left bank. Thirteen fish were detected more days on the left bank than the right. Many fish (53) were detected an equal number of days at both banks (Table 17).

Table 17. Chinook detection locations near the Chief Joseph Dam by number of days using fixed receivers.

Detections by day	Number
Fish detected more days on right bank (Site 03)	91
Fish detected on more days on left bank (Site 02)	13
Fish detected an equal number of days at both sites	53
Total	157

We also looked at fish location by day to see where fish spent most of their time throughout the study (Figure 16). We looked at the number of individual fish detected over time by the receiver sites on the right and left banks of the river. The location for each fish was determined by where the signal was the strongest (maximum power) by hour and the number of fish per day was determined by the final location of the each fish every day. Fish were distributed on both sides of the river throughout the study period, although significantly more fish were found on the right bank (Wilcoxon signed rank, $P(|t_{148}|=3171) <0.05$).

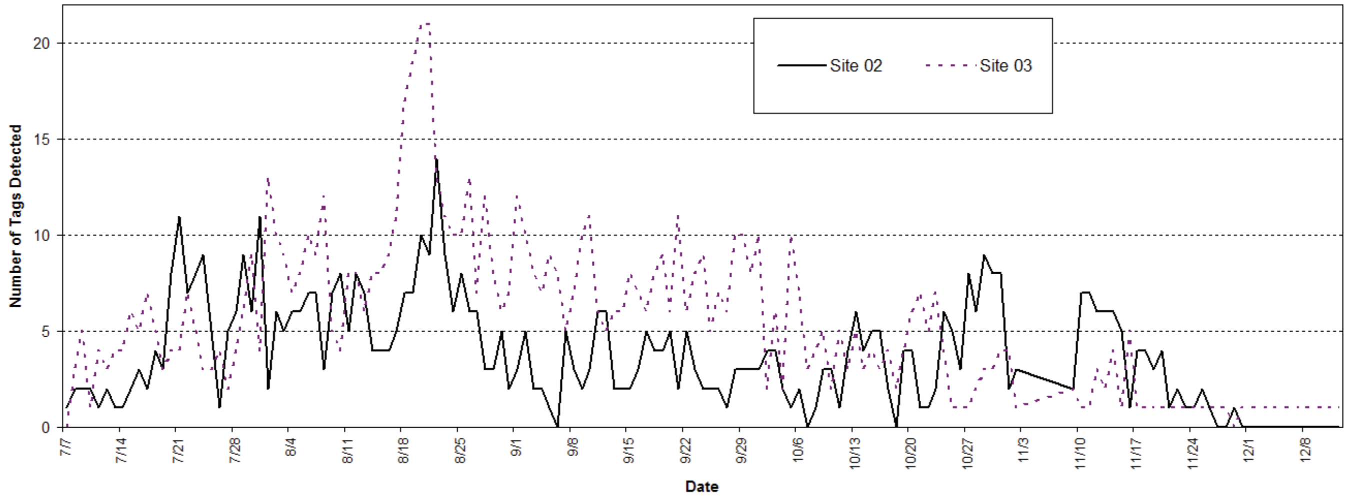

Figure 16. Daily location, right (02) or left (03) side of bank, for fish at the base of Chief Joseph Dam using fixed receivers.

2.4.2. Fate of adults that congregate near the ladder

The base of Chief Joseph Dam is a popular location for a tribal snag fishery. We expect that many fish that congregated here were harvested. We tried to evaluate unreported harvest of tagged fish by looking at the power of the signal of radio tagged fish, where high power would indicate the fish had been removed from the water and so harvested. However, we found that some tagged fish detected with a high power signal were re-detected at later dates in tributaries such as the Okanogan and Methow. Power was therefore not an accurate means of assessing harvest. We also noted that although the tribal fishery occurs on both sides of the river, the right bank of the river seemed to be a more popular place to fish than the left bank.

The fate of fish that remained in the Columbia River is discussed more thoroughly in the sections “Migration and movement patterns of fish following their passage through Wells Dam.” This seems appropriate for two reasons. The first is that many fish never moved into Columbia River tributaries and the second is that we found that fish that congregate at the base of the dam continuously move between the dam and the Colville Tribes Trout Hatchery. As a result, we describe the fate of adults in the Columbia River for the entire area above Wells Dam.

2.5 Migration and movement patterns of fish following their passage through Wells Dam

Objective 3. Identify areas where Chinook hold before they spawn and their migration patterns as they move into the Methow, Okanogan, and Similkameen tributaries.

2.5.1. Fates of Radio Tagged Chinook

All detected radio tagged Chinook were categorized based on their uppermost destination and their migration pathway to reach that destination or capture in a fishery (Table 18). There were many locations where the habitat supports both holding and spawning, as evidenced by Figure 17. Of the 280 fish detected, 117 (41.8%) did not move out of the mainstem Columbia River. The remaining 163 (58.2%) migrated to the Similkameen, Okanogan, or Methow tributaries. Of the fish that migrated to the Okanogan and Similkameen Rivers about half moved directly and the other half migrated upstream in the Columbia in the vicinity of the Colville Tribes Trout Hatchery or Chief Joseph Dam prior to returning downstream and entering the Okanogan. For the 35 fish that migrated to the Methow, 13 swam directly into the Methow while the other 22 exhibited an upstream migration towards Chief Joseph Dam before returning downstream to enter the Methow.

Fish whose upper destination was the Mainstem Columbia River were most often detected moving back and forth between the Colville Tribes Trout Hatchery and Chief Joseph Dam (n=96, Table 18). Whether this circular pattern is clockwise, counterclockwise, or mixed is unknown because the receiver at the trout hatchery did not distinguish between the sides of the river that fish moved. However, as discussed in the previous section, most fish arrived at the Chief Joseph Dam from the right bank.

Six fish were last detected between the confluence of the Methow River and the Colville Trout Hatchery and two fish moved into the Methow River, then turned around and returned to the Columbia. Of the six fish that were initially detected by the Okanogan River receiver, the detection pattern indicates that one fish died in the Lower Okanogan River below Site.06. The tag could have been regurgitated but that is unlikely since regurgitation typically occurs soon after tagging. The remaining 5 fish could have been pre-spawn mortalities, spawned in the mainstem, or been captured in a fishery but not reported. The results for these fish as well as those that were only detected in the Columbia mainstem raises the question whether fish spawned in the mainstem. The 7 fish detected below the Methow confluence could have been mortalities or they could have spawned just below the dam, which holds a known spawning area (Murdoch and Miller 2001).

Table 18. Upper destination and travel pattern history of individual fish that were detected using fixed and mobile receivers during the Chinook migration and movement study. The "CJD" refers to the base of Chief Joseph Dam and "CTH" refers to the Colville Tribes' Trout Hatchery.

Upper destination	Migration path	Number	River total	Reported catch in fisheries
Mainstem Columbia	Between CTH and CJD	96	117	15
	Between Methow confluence and CTH	6		2
	Methow River then Columbia	2		0
	Okanogan River then Columbia	6		0
	Below Methow confluence (or Wells only)	7		0
Okanogan	Directly into Okanogan	27	58	2
	CJD or CTH then into Okanogan	31		0
Similkameen	Directly to Similkameen	38	70	0
	CJD or CTH then into Similkameen	32		1
Methow	Directly into Methow	14	35	0
	CJD or CTH then into Methow	20		0
	CJD, CTH, Okanogan to Methow	1		0
Total number	All	280	280	20

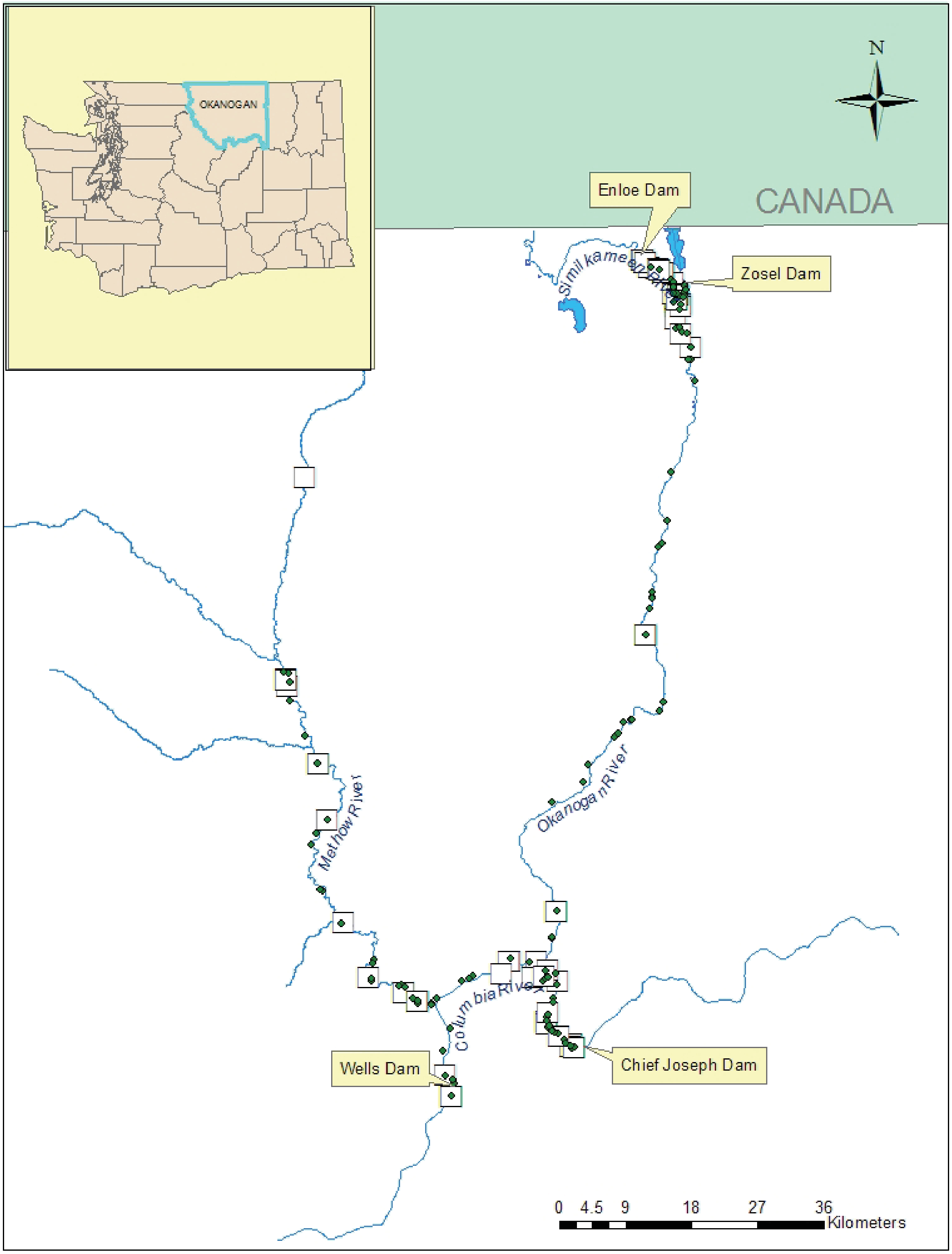

Figure 17. Map showing radio tagged Chinook during holding (white squares) and spawning (dark circles) periods, based on date when fish were first observed spawning. Data was collected from detections of fixed and mobile receivers.

2.5.1.1. Final fate for Chinook whose uppermost destination was the Mainstem Columbia

The fate of the radio tags for the 117 fish that remained in the Mainstem Columbia is shown in Table 19. Of these fish, 17 tags were returned by fishermen who had harvested tagged fish and these fish definitely died before spawning. Fourteen tags were categorized as suspected mortality because no movement occurred over a period of weeks and the tag could not be recovered because of deep water or riprap. Whether these fish spawned is unknown. Although it was suggested to us that Chinook redds had been observed near Site 02 as well as in Foster Creek (a very small tributary just below Chief Joseph Dam), we did not see redds in these areas. Chinook were observed in an eddy near Site 02 but no redds were observed. Of the 5 tags that were recovered in dead fish, two fish appeared to have spawned. These fish were found above the confluence of the Columbia and Okanogan Rivers and had one or both of the following characteristics: contained only a few eggs, which indicated they were "spawned out"; worn tails which indicated they had dug redds. The remaining 3 fish were too deteriorated to evaluate. Eighteen tags were recovered without a carcass. These tags were found lying on the bank, under leaves, in the shallow portions of the water near the sides of the Columbia, or in riprap. These tags are unlikely to have been regurgitated because tag regurgitation typically occurs soon after the fish are released. Consequently, we would have recovered them at the Starr Boat Launch or in the transport truck. More likely possibilities are that a fisherman removed the tag or that an animal ate the fish. At the beginning of the study, fish may have been dead a month before we located the tag because the priority was tagging and tracking surveys. As a result, the 1-2 hours needed to locate a specific tag could not be performed early in the study.

The fate of the remaining 63 fish that remained in the Columbia River is unknown. These fish were detected at least once in the mainstem Columbia, were never detected in a tributary, and were not detected continuously in one location (indicating mortality). Fourteen of these 63 fish were last detected below the confluence of the Methow and Columbia Rivers. A map of fish by their final detection location using ArcGIS (version 9.1; Figure 18) can be used to further investigate areas of potential holding and spawning in the mainstem Columbia. During surveys, researchers never observed spawning or redds in the Columbia River.

Table 19. Fate of radio tags and radio tagged Mainstem Columbia River Chinook.

Fate of radio tags	Number of tags
Returned by anglers	17
Unmoving detection pattern indicates fish died	14
Recovered from a carcass	5
Recovered but no carcass	18
Unrecoverable and unknown	63
Total	117

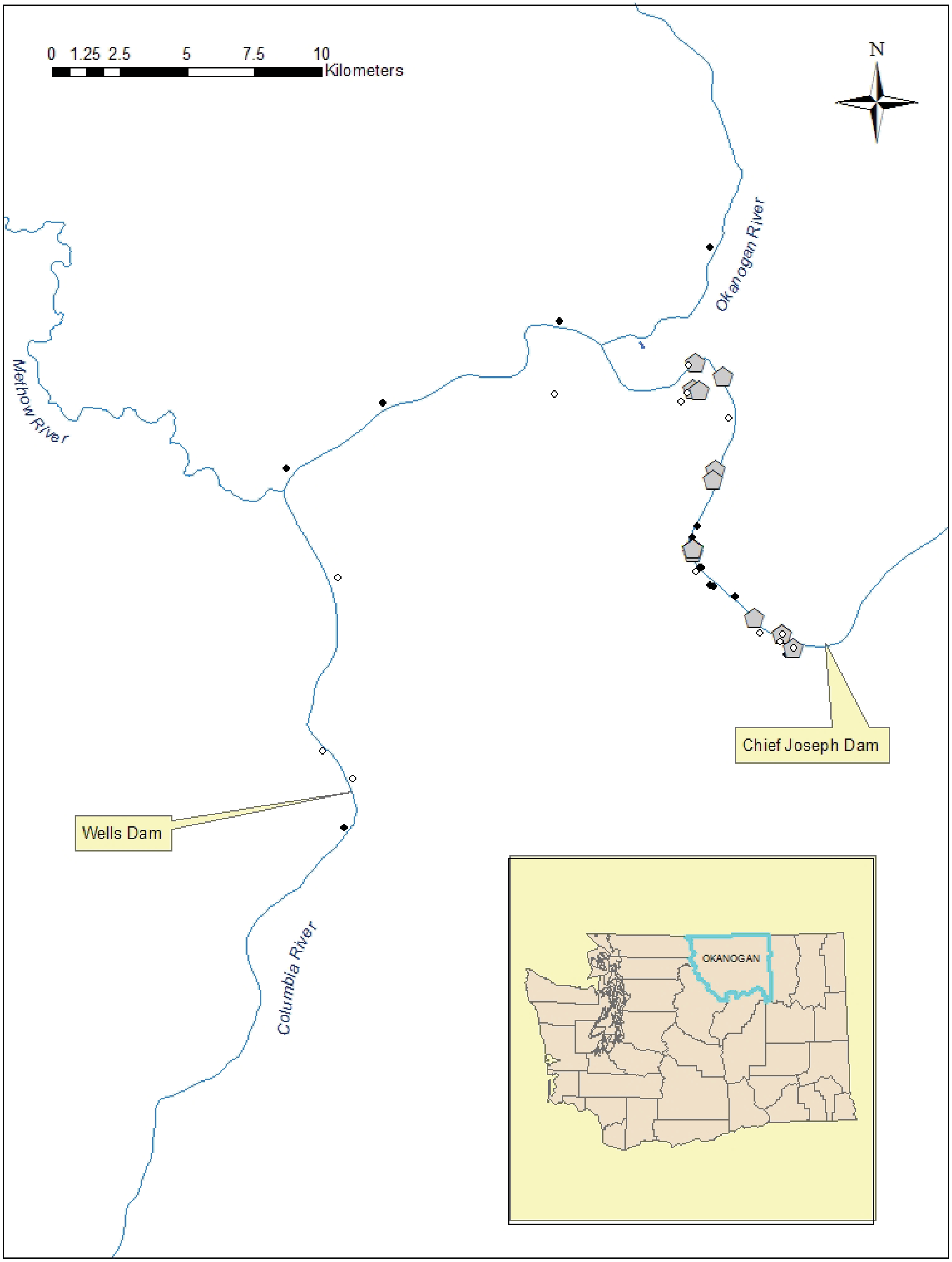

Figure 18. Map showing radio tagged Chinook that remained in the Columbia River by presumed mortalities (dark circles), recoveries (white circles), and unknown fate (gray pentagon). These areas may be mainstem spawning areas. Tags that were recovered by anglers are not shown.

To further understand the fate of mainstem Columbia River fish, the detections were broken down by river section (Table 20). The column "Tags not recovered" is of interest because these fish may have spawned in the mainstem. The fish that were never located above Wells Dam could have been mortalities or they could have been fallbacks that spawned in the area just below Wells Dam.

Table 20. Radio-tagged Chinook detected in the mainstem Columbia River grouped by detection area. Data collected using fixed and mobile receivers, mobile surveys, spawner surveys, and tag returns from anglers.

<table>
<tr><th>Area of most upstream detection</th><th>River section</th><th>Number detected</th><th>Number caught in fishery</th><th>Number recovered (non fishery)</th><th>Total recovered</th><th>Tags not recovered</th></tr>
<tr><td>Near CJD</td><td>C-05</td><td>92</td><td rowspan="2">15</td><td rowspan="2">17</td><td rowspan="2">32</td><td rowspan="2">60</td></tr>
<tr><td>Between CTH and CJD</td><td>C-04</td><td>10</td></tr>
<tr><td>Between Methow confluence and CTH</td><td>C-02 and C-03</td><td>9</td><td>2</td><td>4</td><td>6</td><td>3</td></tr>
<tr><td>Between Wells Dam and Methow confluence</td><td>C-01</td><td>3</td><td>0</td><td>2</td><td>2</td><td>1</td></tr>
<tr><td>Never heard above Wells Dam</td><td>C-00</td><td>3</td><td>0</td><td>0</td><td>0</td><td>3</td></tr>
<tr><td>Entire</td><td>All</td><td>117</td><td>17</td><td>23</td><td>40</td><td>77</td></tr>
</table>

2.5.1.2. ***Final fate for Chinook whose uppermost destination was the Okanogan or Similkameen Rivers***

Not all fish that migrated to the Okanogan River proceeded onto the Similkameen River, confirming reports that a fair amount of spawning occurs in the Okanogan River (Chris Fisher, Colville Tribal Biologist, personal communication, 2006). Of the 58 fish whose uppermost destination was the Okanogan River, 27 went directly into the Okanogan River. A few more, 31, went to the trout hatchery and base of Chief Joseph Dam before turning around and moving up the Okanogan River.

Seventy additional fish moved through the Okanogan River and into the Similkameen tributary. Of these fish, about half (38) headed directly to the Similkameen while the rest (32) were first detected near the trout hatchery and base of Chief Joseph Dam.

The number of fish following these two distinct travel patterns is shown in (Figure 19). Regardless of the month that Chinook passed Wells Dam, a greater proportion always first migrated to the Chief Joseph Dam before moving into the Okanogan Basin than moved directly into the Okanogan Basin. The average passage time between Wells Dam and Site 06 in the Okanogan River was greater for fish that were first detected at Chief Joseph Dam or the trout hatchery than for fish moving directly into the Okanogan.

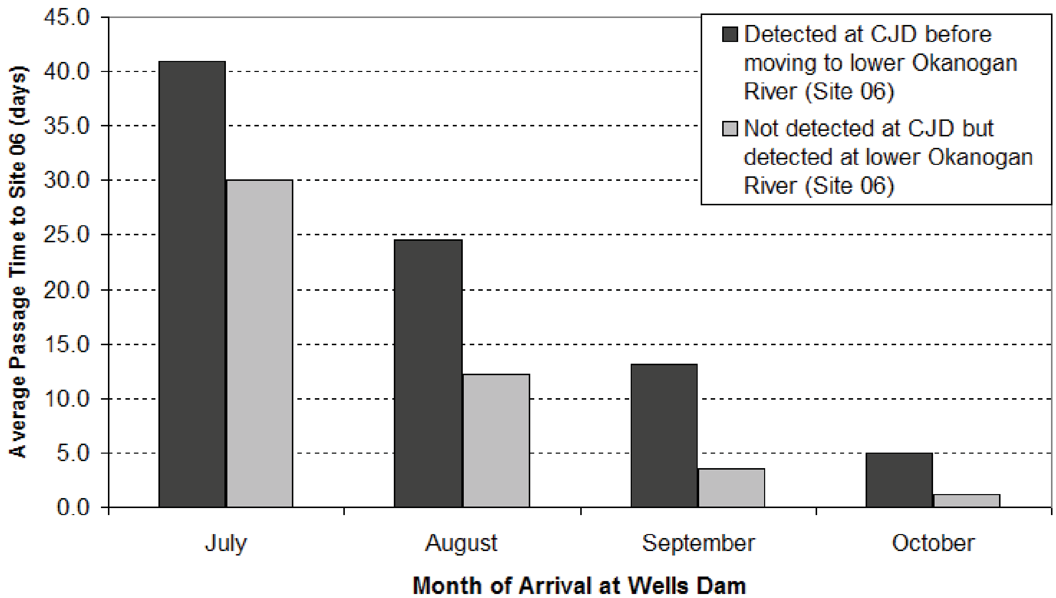

Figure 19. Migration pattern of Okanogan/Similkameen Chinook for each month of arrival at Wells Dam using fixed and mobile receivers.

Figure 20 compares the cumulative number of fish detected in the Okanogan over the study period with the number tagged and the average weekly water temperature (collected near Omak). Most fish moved into the Okanogan River after week six, which corresponds well to the drop in water temperature. During weeks 1 through 5, the average weekly water temperature ranged between 21.0 degrees and 23.7 degrees Celsius (Figure 20). The maximum weekly water temperature ranges between 23.5 degrees and 26.3 degrees Celsius. As temperature quickly declines after week 6 there is a rapid increase in fish movement into the Okanogan that exceeds the rate of fish tagged and released.

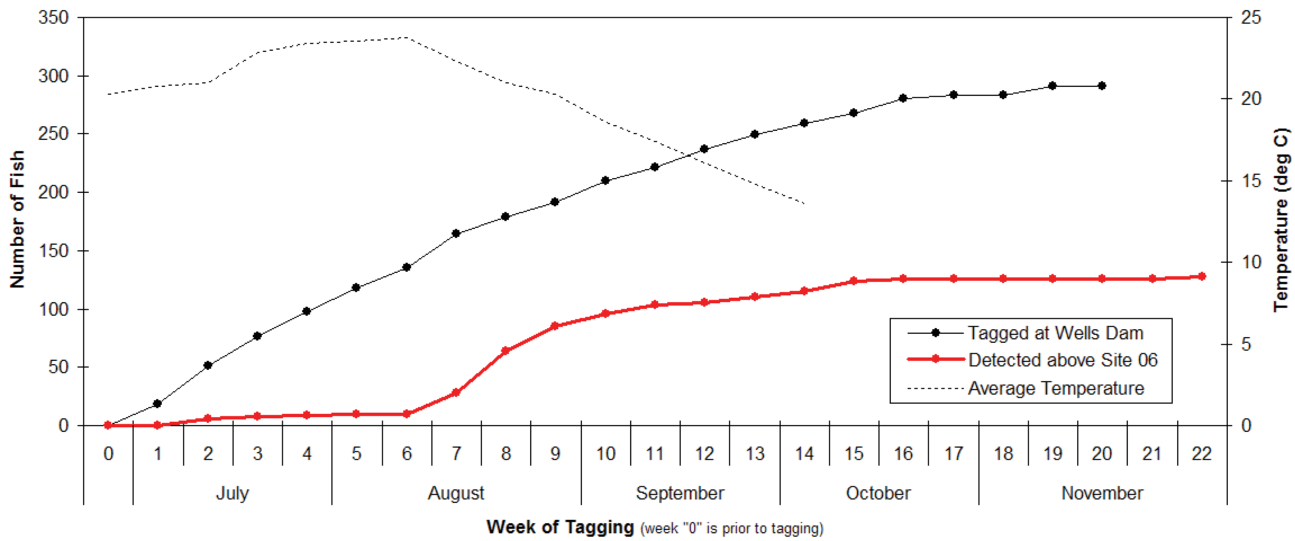

Figure 20. Cumulative number of Chinook above lower Okanogan River (Site 06) and cumulative number tagged compared to average weekly temperature. Area where red line flattens represents times that fish were not moving into the Okanogan River (Site 06). Data collected using fixed and mobile receivers.

Fish that arrived at Wells Dam in July and were detected at Chief Joseph Dam had the highest average passage time to the Okanogan River, Site 06, which was just above the Monse Bridge. Fish arriving at Wells Dam earlier and moving to the base of Chief Joseph Dam have a longer average passage time than fish that arrived later and were not detected at Chief Joseph Dam (Figure 19).

For fish that migrated to the Okanogan Basin, we compared the passage time for Chinook that directly migrated to the Okanogan system with Chinook that first held at the tailrace of Chief Joseph Dam and the trout hatchery (Figure 21). Most fish that took less than a week moved directly into the Okanogan system. However, passage times to spawning areas varied regardless of whether or not fish held in the mainstem Columbia River.

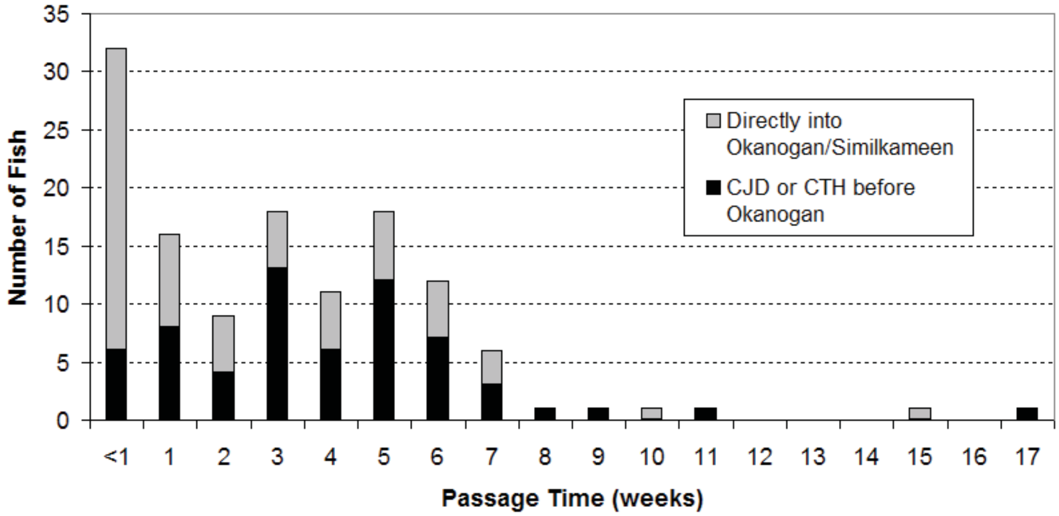

Figure 21. Passage time for radio tagged fish by migration pattern, direct movement into Okanogan system or holding at tailrace of Chief Joseph Dam and hatchery. Data collected using fixed and mobile receivers.

Fish travel time for the 50.7 km between Site 06 on the lower Okanogan River (just above the Monse Bridge) and Site 05 in the upper Okanogan (in the town of Riverside) ranged from 1 to 37 days (Figure 22). This was calculated by subtracting the last detection at Site 06 from the first detection at Site 05 and rounded to nearest whole day. These results indicate there may be significant holding areas between the towns of Monse and Riverside. To learn if fish were more likely to travel in the Okanogan River during the night or day, we evaluated the night and day movement of the 28 fish that moved from the lower Okanogan River to the lower Similkameen River (Table 21) in a 24 hour period or less. Most of these fish moved during daylight hours.

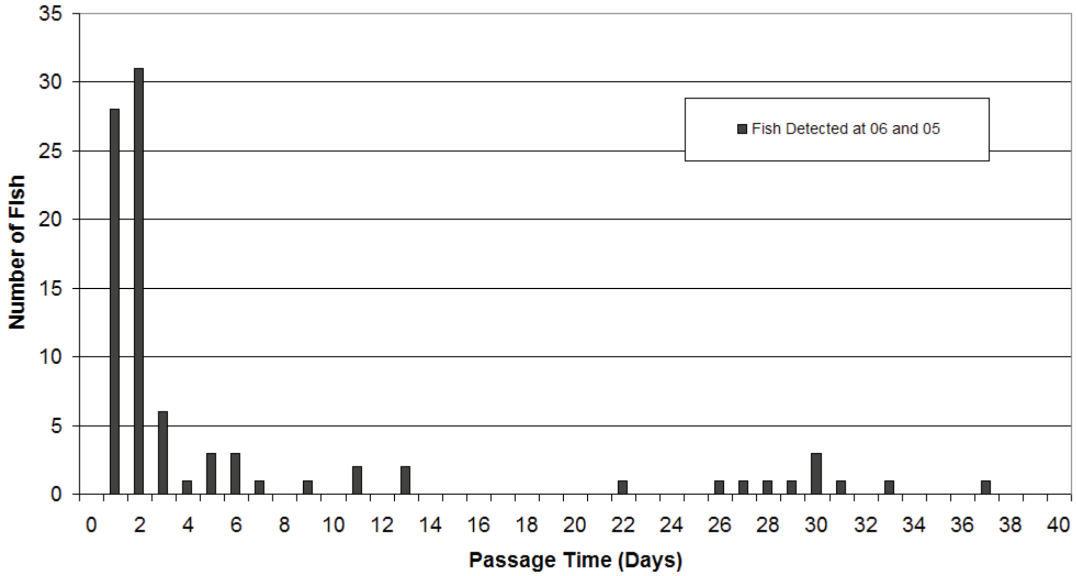

Figure 22. Radio tagged Chinook passage time from Lower Okanogan River (Site 06) to Riverside (Upper Okanogan River, Site 05). Time was calculated by subtracting last detection for fish at site 06 prior to their detection at site 05 from the fish's first detection at site 05. Data was collected using fixed and mobile receivers.

Table 21. Detections of fish by day and night at the Okanogan and Similkameen River fixed receiver sites for fish that took a day or less to travel between sites. The Okanogan River site is shown by last detection and the Similkameen River site is listed by first detection.

Site 06	Site 05	No. of Fish
Day	Day	12
Day	Night	5
Night	Day	8
Night	Night	3
Total		28

2.5.1.3. Final fate for Chinook whose uppermost destination was the Methow River

Of the fish whose uppermost destination was the Methow River, 14 went directly to the Methow. This includes one fish that ultimately moved into the Chewuch River, a tributary of the Methow River that is not typically used by summer/fall Chinook. Most (20) of the fish migrating into the Methow moved between the trout hatchery and base of Chief Joseph Dam before entering the Methow River. One fish chose a unique path, migrating between the trout hatchery and Chief Joseph Dam, and then moving into the Okanogan before turning around and heading downstream and into the Methow.

2.5.1.4. Capture in fishery

Tags were recovered from 21 radio-tagged fish captured in sport and tribal fisheries (Table 18), with most fish captured (17) from the group that moved between the trout hatchery and the base of Chief Joseph Dam. This number is likely less than the actual number captured because despite a $25 reward, not all fishers returned tags. Some tags were detected in residences but were never returned. A fisher told one of us (Schwartz) that he planned to remove the tags from fish he captured and throw the tags back into the water. Detections of unrecoverable tags later in the season suggest that this occurred.

3 Discussion

Charles Darwin said, “It is not the strongest of the species that survive, nor the most intelligent, but the one most responsive to change.” During the past two hundred years, Chinook in the Columbia River have been required to change a great deal in response to human activity. Chinook are well known for their plasticity and ability to evolve into distinct populations that correspond with varied habitats. As a result, differences such as run timing, preferred tributary, preferred side of the river, spawning location, size, age of return, and genetics, among others, can all be indicators of adaptation within and among a population.

Recently the Colville Confederated Tribes renewed efforts to build the final mitigation hatchery that had been planned for Chinook production lost because of the Grand Coulee Dam. They recognized that as part of the planning process, key questions about Chinook migration and movement patterns above the Wells Dam needed to be answered. These questions were aimed at learning if population substructuring exists among the Chinook that return upstream of Wells Dam, which is reflected in life history differences, so that selective fishing gears can appropriately target broodstock for the hatchery. To address these questions, we considered the history of these fish and studied their current behavior using biological data and radio telemetry tracking equipment.

3.1 Historic information for Chinook above Wells Dam

Fulton (1968) was one of the first biologists to summarize the status of Chinook populations in the Columbia River. The Columbia River once housed enormous runs and populations of Chinook salmon, which were arbitrarily divided into three runs, spring, summer and fall, based on adult return timing from the ocean. Spring and summer run Chinook formerly populated almost the entire length of the Columbia River while the fall run populated the lower and middle portions. Spring Chinook produce stream-type (age 1+) smolts, while summer and fall Chinook produce sub-yearling (age 0+) smolts. The mid-Columbia area was defined as the area between the McNary and Chief Joseph Dams while the upper Columbia consisted of the area above the Chief Joseph Dam. Fulton (1968) noted that spring and summer runs typically spawned in mid-Columbia tributaries, with the spring groups generally spawning in small and medium-sized tributaries and summer groups generally spawning in the intermediate and large tributaries as well as in middle reaches of the mainstem.

Following construction of the Grand Coulee Dam, spring and summer runs were intercepted at Rock Island Dam (1939-1943) and transplanted into the Wenatchee, Entiat, Methow, and Okanogan Rivers (Fulton, 1968). Considerable area in the Okanogan River and the entire area above the Chief Joseph Dam (including the mainstem) were important areas for spring and summer run Chinook that are no longer in production (Fulton, 1968). In the present day, spawning area in the Okanogan River consists of intermittent riffles in the Okanogan River from its confluence with the Columbia to Zosel Dam and the lower 2 km of the Similkameen River (Fulton, 1968).

In the mainstem Columbia, spring and summer Chinook spawning formerly extended above the Grand Coulee Dam to Windermere Lake, 958 km above the mouth of the Columbia River. Fish that spawned in this area were large (18–27 kg), usually appeared during the last week of August, and began spawning shortly thereafter. This stock was transplanted and Fulton (1968) notes that fish of this size spawn in the Wenatchee River, mainstem of the Columbia River, and may spawn in the mainstem below Chief Joseph Dam.

For fall Chinook, Fulton (1968) wrote that the peak of runs destined for the middle reaches of the Columbia arrived at Bonneville Dam around the first of September and between one and two weeks later moved through Dalles and McNary dams. These fish spawned in mainstem areas above McNary Dam (rkm 879). Among others, this area formerly included Wells, Chief Joseph, and Grand Coulee dams, but the pools from these dams inundated much of the spawning area (Fulton, 1968). Further, areas were taken out of production when the impassable high Grand Coulee Dam and the Wells Dam, just completed at the time of Fulton’s report, inundated most of the remaining fall Chinook spawning areas. These changes left spawning habitat scattered from above the McNary Dam pool to Priest Rapids Dam and a small area near the mouth of the Wenatchee River (Fulton, 1968).

At the time of his summary, Fulton (1968) stated that the fall Chinook run had declined markedly and noted that the harvest of fall Chinook did not begin until about 1890, after a sharp decline in the late 1880’s of the more highly prized spring and summer runs. From 1928 to 1966, the fall run usually made up a major portion of Chinook catch (Fulton, 1968). In the present day, summer/fall Chinook runs have rebounded following low abundance about 10 years ago. Currently SaSI (WDFW, 2003) cites the Okanogan Summer Chinook and Methow Summer Chinook populations as healthy and notes that studies have shown only minor differences between summer and fall Chinook in the Upper Columbia River. Consequently, Washington State does not distinguish summer and fall Chinook. In contrast, the Colville Confederated Tribes expect there may be distinct Chinook summer and fall components for this region.

3.2 Tagging, tag recovery, and tag evaluation

3.2.1. Tagging

We radio tagged a greater proportion of late migrants because historical spawning survey information suggested that traditionally the Okanogan River received higher densities of Chinook later in the season (fall Chinook), likely because of the need for the thermal barrier created by warm water temperatures to dissipate (Stephen Smith, personal communication, 2005). We used estimates from a previous study (Stuehrenberg et al., 1995) as a guide for the number of fish to tag. We tagged 291 fish and found that over twice the number expected (based on the Stuehrenberg et al., (1995) study) moved to the base of Chief Joseph Dam.

Tricaine methanesulfonate (MS-222) is the anesthetic most often used in fisheries applications. However, the FDA requires a 21 day withdrawal period prior to human consumption, and because these fish were susceptible to being caught in the sport and tribal fisheries, we chose to use CO_2 instead. We made slight modifications from the original technique developed by a Canadian hatchery worker (Jack Tipping, 2004, WDFW, personal communication). Use of CO_2 as an anesthetic does involve more effort than the use of MS-222, in part because it requires carefully monitoring dissolved oxygen and pH.

One problem encountered in telemetry studies is tag regurgitation. In our study, the rate for tag regurgitations that occurred during the fish's recovery and transport or in the immediate vicinity of the release site was 12.35%. To prevent regurgitation, we put rubber bands around the tags (Keefer et al., 2004), but our rate was not as low as that of Keefer et al. (2004), 5.6%, or of Garcia et al. (2004), 3%. One of us (Waldbillig) had prior experience applying telemetry tags and the rest of the tagging crew quickly became efficient. We found regurgitated tags with the antenna caught on grates in the transport tank and expect this is why our regurgitation rate was higher than expected. However, because the tags were regurgitated soon after tagging, they were retrieved, sanitized, and placed in different fish.

Wells Dam has fish ladders on both the west and east sides of the Columbia River. The choice of ladder that fish were collected from on a given day was based on availability, as determined by broodstock collection efforts and ESA requirements that limit trapping fish to three days per week. During the first two weeks of the study we were limited to tagging fish at the west ladder and during the last three weeks we were limited to tagging fish at the east ladder. There were many weeks when both ladders were used. Eltrich et al. (1995) reported that strays and hatchery fish are most apt to pass through the west ladder while local and natural Chinook are most apt to pass through the east ladder. We did not find a difference in spawning destination based on which ladder fish used to pass and this could be because we tagged few hatchery fish.

3.2.2. Tag recovery

We expected to get additional information from jaw tagged fish to corroborate what we learned from the telemetry study. However, we did not recover as many jaw tagged fish as expected. Most were returned from fishers because some spawning ground surveyors were not aware to look for jaw tags until late in the season. The nearly 10% return rate of jaw tags we received corresponds well to the 10% return rate of jaw tags we received during the first year of a Lower Columbia River study (VanderHaegen et al., 2004). Because of the smaller area and more concentrated sampling for this study, we expected the return rate to be higher. Based on the Lower Columbia River study, if this study were repeated for a second year, the return rate of jaw tags could double because of an increase in angler and surveyor awareness.

Another potential reason for the low rate of jaw tag returns could be tag retention. Survey samplers commented that they found fish with holes in their mouths, indicating jaw tags had been present. Samplers also found jaw tags hanging loosely from fish's mouths. Jaw tags were typically attached by the same people as had attached jaw tags to spring Chinook in the lower Columbia, so if a tag retention problem existed for summer/ fall Chinook at Wells Dam, perhaps it was a result of the advanced maturity of these fish.

Radio tags and jaw tags were recovered from tribal and sport fishers and by spawning ground surveyors. Zhou (2002) showed that spawning ground surveys are generally biased by the probability of recovery, with surveys tending to underestimate the number of small fish and tending to overestimate those of large fish and females. Consequently, this bias likely occurred for jaw tags recovered during surveys. For this study, such a bias is not problematic. During mobile surveys, some radio tags were found on the bank of the Columbia River with no carcass. In future studies it will be desirable to locate these tags more quickly to evaluate the fate of the fish as a mortality, harvest, or spawned carcass.

3.2.3. Tag evaluation

To evaluate migration and movement patterns, we had the option of analyzing the tagged fish by their final location or by their uppermost destination in a Columbia River tributary. By using uppermost destination, errors caused by carcasses floating downstream and picked up by receivers were avoided. The difference between the two options results in more fish noted in the Similkameen River when uppermost destination is used (Figure 23 and Figure 24).

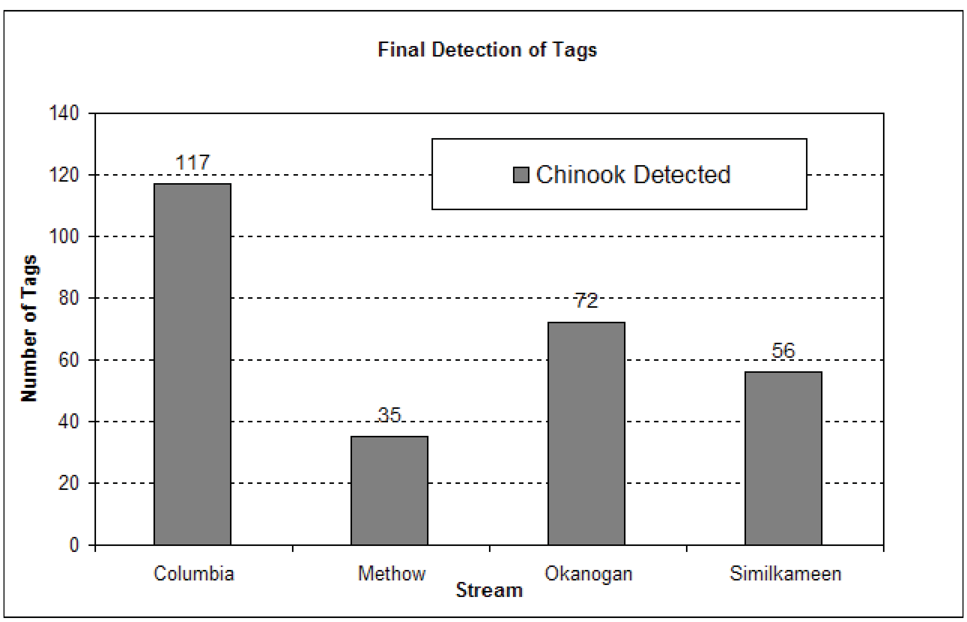

Figure 23. Number of tags by river using final detection.

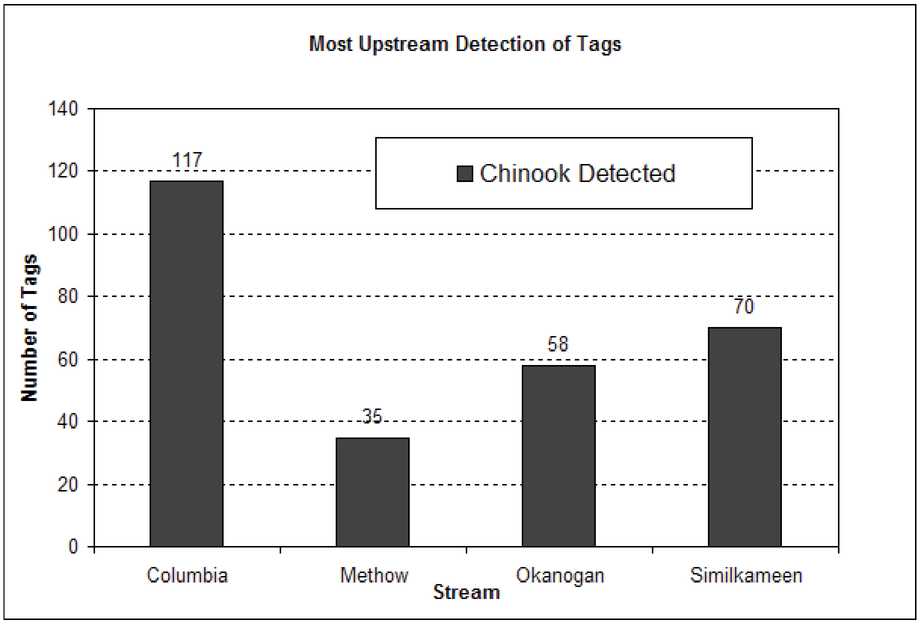

Figure 24. Number of tags by river using uppermost detection.

3.3 Study questions

3.3.1. Arrival at Wells Dam relative to destination and spawning time

The first tasks of this study were to learn if there is a relationship between arrival time at Wells Dam relative to destination and spawning time. To answer this, we identified the locations and arrival time of fish that spawn in the upper portion of the Columbia Cascade Province relative to their passage time at Wells Dam, using fixed and mobile receivers to detect the first uppermost detection of radio tagged fish as a surrogate for spawning ground arrival time. We also evaluated these tasks based on dates when we observed spawning occurring in the Okanogan system.

Using the arrival timing of Chinook at Wells Dam based on migration to known spawning grounds, we determined that arrival timing at Wells Dam is positively correlated to spawning location and to spawning ground arrival date. Most spawning occurred between 6 and 12, October.

We found a similar result using the arrival time to the uppermost detection site. Here, we found that the fish that arrive at Wells Dam earlier (July and August) are more likely to migrate to the Similkameen and Okanogan rivers. In contrast, fish that arrive at Wells Dam later (after July) are more likely to migrate to the Methow or mainstem Columbia rivers. At a finer scale, for Chinook that migrate to the Okanogan Basin, fish that arrive at Wells Dam earlier (July) are more likely to migrate to the Similkameen River and fish that arrive later (after August) are more likely to migrate to the lower Okanogan River.

We also learned that Chinook migrating to the lower Okanogan River tend to pass Wells Dam later in the year. Many Chinook remained in the mainstem and did not migrate to a Columbia tributary. These fish were more likely to pass Wells Dam during the early months. We further found a correlation between arrival time at Well's Dam and spawning date, with earlier arriving fish more likely to arrive at the spawning grounds earlier. There was much variation, and few fish returned during the later months of October and November, which could be the result hatchery supplementation practices not supporting the tail end of the run (Pascual et al., 1995).

These differences could indicate adaptations within or among the population(s). Genetic analysis of individuals from the groups displaying the different behaviors observed in this study might provide evidence of associated genetic substructuring among Chinook above Wells Dam. The potential for population differences is of particular interest because this information can be used to direct where progeny of Chinook produced at the planned hatchery should be planted. For instance, based on the results of this study, the progeny of early arriving Chinook should be planted in acclimation ponds in the upper Okanogan Basin while progeny of late arriving Chinook should be planted in acclimation ponds in the lower Okanogan River and potentially in the mainstem provided that spawning is verified for the mainstem. Further, DNA analysis of the fish that remained in the mainstem Columbia could address whether the mainstem group is genetically distinct from tributary spawners.

3.3.2. Hatchery ladder placement

Additional study goals were to learn if the proposed hatchery ladder is suitably located to draw adults into the planned hatchery and to evaluate the fate of adults that congregate near the proposed ladder. These were approached by evaluating the patterns of fish that migrated to Chief Joseph Dam in a number of ways. The ladder location is planned to be on the right bank (north shore) of the Columbia River near the base of Chief Joseph Dam. We found that most fish (70.06%) migrate to the dam from the right bank and that 87.90% were detected by receivers on both sides of the river. We also looked at fish location by day to see where fish spent most of their time throughout the study. Although fish were distributed on both sides of the river, significantly more were found on the right bank each day of the study period. Once the hatchery is built and has juvenile salmon, the ladder will likely increase in attractiveness to adult salmon because of the chemical attractant (Hasler et al., 1978). Overall, these results indicate that fish prefer the right bank although they move back and forth at the base of the dam, and they further indicate that fish should find the hatchery ladder.

3.3.3. Migration and movement patterns

Because the final goal of this study is to identify areas and groups of fish appropriate for broodstock collection, we evaluated the migration and movement patterns of Chinook following their passage through Wells Dam. This included identifying areas where Chinook hold before they spawn and their migration patterns as they move into the Methow, Okanogan, and Similkameen tributaries.

Prior to the study, local knowledge held that fish mill at the base of the Chief Joseph Dam. We found that the area is much larger, encompassing the Chief Joseph Dam to the Colville Trout Hatchery. The attraction of fish to the tailrace of the dam is understandable because of high flows, cooler temperatures in the deep water, and this is the furthest extent that can now be reached for migrating fish. Similar conditions likely contribute to the migration pattern of fish entering the Similkameen River and holding near the base of Enloe Dam before moving back down to areas lower in the Similkameen that provide better spawning habitat. The attraction fish had to the hatchery is less clear.The hatchery water temperature is 10 degrees celsius cooler. There are various reasons why this occurred. Chinook could be attracted to the chemical odors in the hatchery effluent (Hasler et al., 1978). This could be a mainstem spawning area, and could be tested by evaluating the substrate or using an underwater camera system (Groves and Garcia, 1998). Another possibility is that the Chinook may have moved within a larger area that extended to the confluence of the Okanogan and Columbia Rivers. This behavior could allow the fish to evaluate the Okanogan River temperature or other characteristics for migration and spawning. This final hypothesis could be evaluated in a future study by placing another receiver below the trout hatchery at the confluence.

Significantly more Similkameen fish were of wild origin (unclipped) compared to fish returning to other locations. However, this result is likely confounded because we only tagged hatchery fish when we could not meet our goals through tagging wild fish.

The large number of radio tagged Chinook that never migrated into the Methow or Okanogan Rivers (41.79%) is very interesting and indicates that mainstem spawning may still occur as historically described (Chapman, 1943; Meekin, 1967; Fulton, 1968). Murdoch and Miller (1999) reported the only 49% of the summer Chinook that migrated upstream of Wells Dam were accounted for on the spawning grounds between 1993 and 1999. This is another indication that mainstem spawning could be occurring. (Recruitment numbers of summer Chinook suggest that post-spawning mortality is not the case). As a result of this study, areas have been identified to look for mainstem spawning or mortalities (Figure 18). For fish that were not detected above Wells Dam, we suspect that they either died or became part of the natural spawning that occurs just below the Wells Dam (Murdoch and Miller 2001).

Chinook remaining in the mainstem were significantly more likely to pass Wells Dam during the early months, July and August, which is likely because they were holding in cooler temperatures. Researchers observed that the few fish tagged at the end of the study, after most spawning had already occurred, did not seem to follow the same migration pattern, timing, or destination as the earlier arriving fish; they were less likely to move to known holding and spawning areas in the tributaries and more likely to remain in the mainstem Columbia. The water temperature had cooled by the time this change occurred. Potentially these late fish are mainstem spawners. It is also possible that because the fish were so ripe when they were tagged, they did not survive the stress of tagging. The fluvial conditions of the Columbia mainstem make it difficult to recover tags so we were often unable to verify whether the tags in the mainstem were still in a fish carcass or whether the fish had spawned.

To evaluate if mainstem spawning is occurring above Wells Dam, we recommend an underwater camera tracking study as developed by Groves and Garcia (1998). This method would suspend underwater video cameras from the bow of a boat to look for spawning activity and redds in mainstem water as deep as 13 m and with velocities to 3 m/s. We recommend the areas shown in Figure 18 be further evaluated for spawning habitat and activity. Because redds were historically observed (Meekin, 1967) downstream of Brewster and upstream of Washburn Island, these may be the most reasonable areas to begin searching for mainstem spawning activity.

Methow-bound fish, like Okanogan and Similkameen fish, hold in the area between the tailrace of the Chief Joseph Dam and the trout hatchery, potentially mixing the stock base for fish entering the planned Chief Joseph Hatchery. Although the current hatchery and wild summer/fall Chinook groups are genetically similar, Washington State science and policy, and to some extent, federal policy, suggest that because the long-term goal is to have fish return to the Okanogan, broodstock collection will likely have to take place in the Okanogan basin.

One radio tagged fish moved into the Chewuch tributary of the Methow River, an area that is generally accepted as spawning area for spring Chinook but not fall/summer Chinook after July 23rd. Either this fish was a spring Chinook that arrived "late", i.e. after the last date of arrival that defines a spring Chinook, or it shows that the belief that summer/fall Chinook do not move into smaller tributaries (Fulton, 1968) does not always hold true.

Previous studies have shown that migration and movement patterns of adult salmon are influenced by genetics, river flow, water temperature, and release site. Below we discuss the possible importance of these factors on Chinook distribution patterns above Wells Dam.

3.3.3.1. __Genetics and potential population differences for Chinook above Wells Dam__

Among upper Columbia River (upstream of the Dalles Dam) Chinook runs, spring Chinook are highly genetically differentiated from summer and fall Chinook throughout this upper basin and within tributaries (Marshall et al. 1995; Waples et al. 2004). In this area, spring and summer/fall Chinook are distinct evolutionary lineages. Spring Chinook populations in different upper basin tributaries (subbasins) are relatively distinct but are more similar to each other than to summer Chinook populations in the same subbasin. For example, Wenatchee River spring and summer Chinook are highly genetically distinct, and Methow River spring and summer Chinook are highly genetically distinct. Wenatchee and Methow rivers' summer Chinook are relatively similar genetically, and both are more similar to "upriver bright" fall Chinook populations (such as Hanford Reach) than to the spring Chinook (Waples et al, 2004). Further, passage data of Chinook through the dams (DART, 2005) shows a bimodal distribution through time for spring and summer/ fall Chinook.

Regardless, the summer/fall Chinook in the area above Wells Dam are genetically similar because of hatchery activities during the past decade. Consequently, it is very unlikely allozyme genetic analysis that was once widely used could identify fish to their river of origin (A.R. Marshall, WDFW, personal communication, 2005). During this study, we collected clips of fins for fish that were radio tagged so that DNA genetic analysis may be done to evaluate possible relationships between Chinook migration and movement patterns and DNA genetics. There was not funding in this study for genetic analysis but the samples have been archived so that as funds become available, this work can be done.

3.3.3.2. __Relationship between river flow and movement patterns__

We found that many Chinook congregate at the base of Chief Joseph Dam before turning around and moving into the Methow or Okanogan systems. Likely this is because of the large discharge in the tailrace of the Chief Joseph Dam relative to the rivers and the considerably lower temperatures. Further, we found that in the Similkameen River fish congregate in pools at the base of the Enloe Dam and expect that this is also due to high flows in this area. These results correspond to previous findings by Unwin and Quinn (1993), who found that fall Chinook salmon in New Zealand mainly stray into rivers with the highest available discharge. In contrast, Garcia et al. (2004) found that juvenile release site was a much larger factor in fall Chinook movement and migration in Snake River tributaries than river flow. Other reasons why the base of Chief Joseph and Enloe Dams were popular holding areas is likely water temperature and depth.

During 2006-2008, spill deflectors (flip lips) will be installed at the Chief Joseph Dam. The purpose of the deflectors is to reduce nitrogen entrainment that can occur when small quantities of water are spilled at Chief Joseph Dam. The late run timing of summer/ fall Chinook makes it unlikely that they will be affected by the change to the spillway because if spill occurs for flood control it will mostly occur in the spring months (e.g. March). Should the deflectors cause changes to the river bottom or flow patterns, effects to Chinook could occur.

3.3.3.3. ***Relationship between water temperature and movement patterns***

Salmon reproductive development often begins far in advance of spawning (King et al., 2004). Fish use proximate cues such as photoperiod and temperature to synchronize spawning around the date that results in ideal conditions for their offspring (Bromage et al., 2001) and warm water temperatures can accelerate ovulation (Pankhurst et al. 1996; Davies and Bromage 2002). Interannual variation in the timing of upstream migration may be correlated with temperature so that high temperatures are avoided (Quinn and Adams, 1996) and especially high temperatures can result in the cessation of migration (Major and Mighell, 1967).

Adult salmonids show migration patterns that appear to reflect avoidance of stressful or lethal temperatures. For instance, many salmon populations leave the ocean and its corresponding opportunity for growth to enter freshwater, even though many months before spawning still remain (Healey 1991; Myers et al., 1998). This evolved behavior may be to avoid high temperatures in the lower reaches of large river systems. Certainly, salmon have been shown to display behavioral thermoregulation during the summer months by holding in deep pools (Berman and Quinn, 1991). Likely, the temperature preferences of adult Chinook are related to physiologic factors that include energy conservation, since holding in the deepest and coldest water available would minimize energy expenditure. For the Methow River, a model has been developed that predicts the coupling of spawning time and fry emergence based on habitat choice and temperature patterns for spring and summer Chinook stocks (Beers and Anderson, 2001). Potentially this model could be used as a method for detecting population differences between summer and fall Chinook stocks in the Okanogan River.

In the Okanogan River, water temperatures have been recorded as high as 26.7 C in July and August (Hatch et al., 1993). Temperatures in excess of 21.1 C are considered to create a thermal barrier for Chinook salmon (EPA and NMFS 1971), with temperatures between 21 and 22 C considered the incipient lethal limit (Coutant 1970) and 25 C being the upper lethal limit (Bell 1991). It was expected that high water temperatures would restrict Chinook access into the

Okanogan system for as much as 3 months after early arriving Chinook pass Wells Dam (Chapman et al., 1994). As a result, we expected that fish would hold in the cooler water at the confluence of the Okanogan and Columbia Rivers as well as in the deep and cooler waters at the tailrace of the Chief Joseph Dam. The 10-year average tailrace temperature for the Chief Joseph Dam for 1994-2003 shows that the temperature peaks on 31 August at 18.96 C and declines rapidly after second week of September (DART, 2005). As a result, we expected to not see many fish moving up the Okanogan River until mid September. However, we found that Chinook trickle into the Okanogan River, even when temperatures are between 20 Celsius and 25 Celsius, and this could indicate that the population has become locally adapted. Most of the fish that ultimately moved into the Similkameen and upper Okanogan spawning grounds passed Wells Dam early in the season but many did not move into these tributaries during the peak water temperatures from mid-July to mid- August. During this period, tag detections indicate that fish hold in the area between the base of Chief Joseph Dam and the Colville trout hatchery as well as the mouth of the Okanogan.

As previously mentioned, we speculate that Chinook may move within an area that extends from the base of Chief Joseph Dam to the confluence of the Okanogan and Columbia Rivers. This behavior would allow the fish to evaluate the Okanogan River temperature or other characteristics for migration and spawning. This would also explain why the fish constantly move back and forth between the base of Chief Joseph Dam and the trout hatchery.
Garcia et al. (2004) did not find that water temperature was an overriding factor affecting fall Chinook movement in the Clearwater River, a tributary to the Snake River, during the months of August and September. Instead, they found that juvenile release site had the largest effect on adult movement patterns.

3.3.3.4. __Relationship between juvenile release site and movement patterns__

The average spawning escapement in the 12 year period before supplementation programs were initiated in the Okanogan Basin was 1,179 fish. During the last 12 years, the average spawning escapement in the Okanogan Basin was 4,654 fish, of which 57% were hatchery origin (A. Murdoch, WDFW, personal communication). Acclimation site (i.e. release location) is known to strongly affect spawning distribution. Young anadromous salmonids imprint to specific areas through olfactory cues (Groves et al., 1968, Hasler et al, 1978) during sensitive periods that coincide with initiation of active seaward movement (Oshima et al., 1969, Pascual et al. 1995, Dittman et al. 1996, Kenaston et al. 2001). Garcia et al. (2004) found acclimation location to be the driving factor in migration and movement patterns for fall Chinook in the Snake River. This study did not evaluate the relationship between juvenile release site and adult movement patterns. However, this should be considered to confirm acclimation and release sites for juveniles from the planned Chief Joseph Hatchery.

3.4.1. Broodstock Collection

The Tribes contracted Mobrand, Biometrics, Inc. to recommend suitable selective fishing gears that could be used to collect broodstock for the planned hatchery. Their report (Mobrand 2004) was followed up by visits from gear experts in 2005. Based on the expert's advice and the holding locations we observed from the radio tag research, we recommend the following gear/location combinations for broodstock collection, and will test these during 2006 (Figure 25):

a. tangle net at the confluence of the Okanogan and Columbia Rivers
b. tangle net in the Okanogan River near the town of Omak
c. beach seine in the Similkameen River
d. stationary trap at the confluence of the Okanogan and Columbia Rivers
e. fishwheel in the Okanogan River as described by Smith (2006)
f. sport fishing at the confluence of the Okanogan and Columbia Rivers or in the town of Omak may also be suitable
g. dipnetting in the Similkameen River pools would likely be successful but fishers experienced in this technique are difficult to find

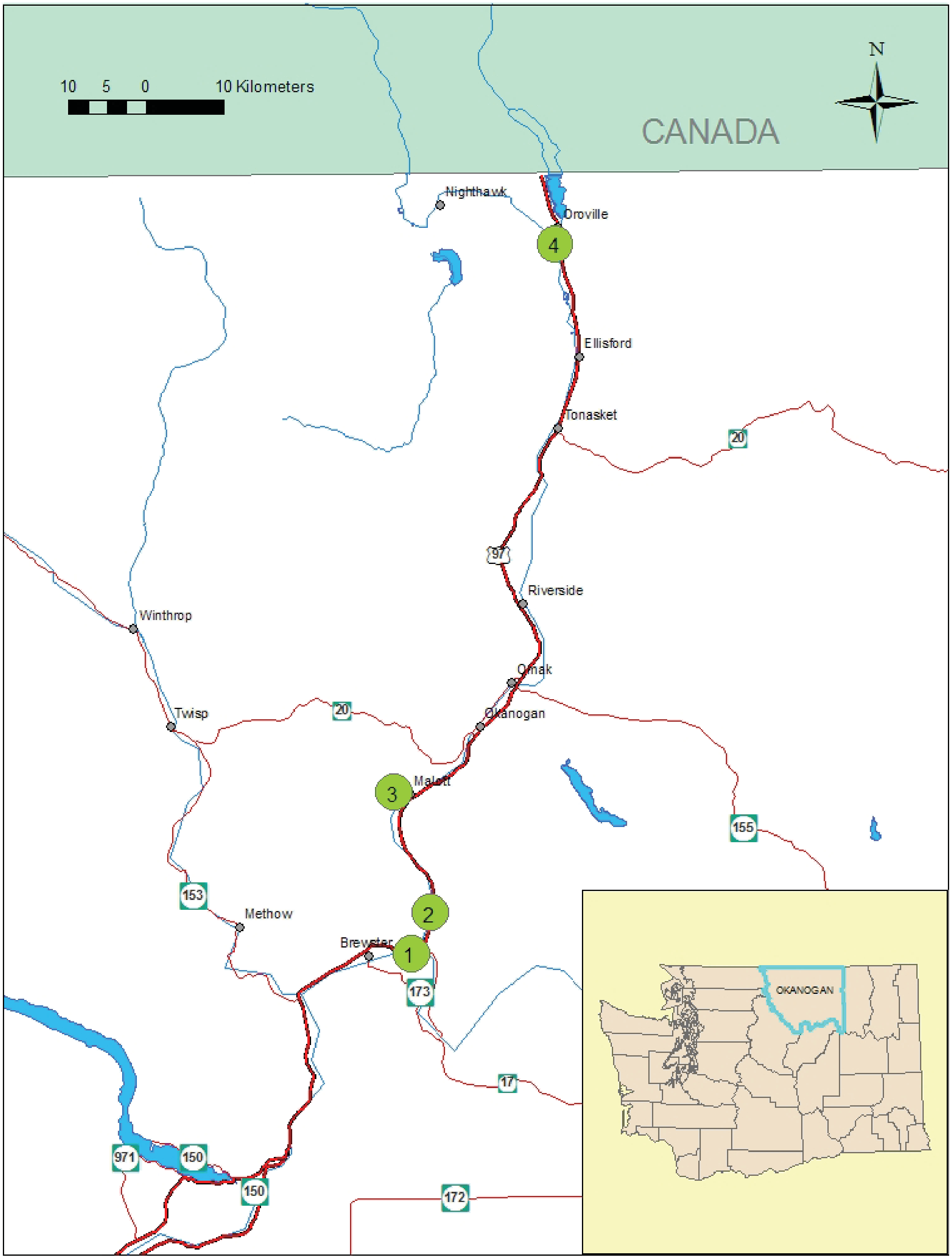

Figure 25. Fishing locations for evaluating selective gears as a broodstock collection method. Fishing locations are listed with a number inside of a shaded circle.

4. Conclusions

1. There is a relationship between the passage time through Wells Dam and spawning location for summer/fall Chinook. Fish that arrive earlier are more likely to enter the Similkameen and upper Okanogan Rivers and fish that arrive later are more likely to migrate to the lower Okanogan River. Consequently, broodstock for the planned hatchery should be collected, spawned, and their progeny planted in a manner that reflects this within population behavior.
2. There is a relationship between passage time through Wells Dam and arrival to the spawning grounds for Chinook in the Okanogan River, fish that arrive at Wells Dam earlier are more likely to migrate further upstream and are more likely to arrive at the spawning grounds earlier.
3. The proposed hatchery ladder is in a suitable location for drawing adults into the hatchery. The fate of adults that congregate near the proposed ladder is harvest; migration to the Methow, Okanogan, and Similkameen Rivers; or to remain in the mainstem Columbia River.
4. A large proportion of fish passing Wells Dam remain in the mainstem Columbia River (41.79%) so we recommend further studies to evaluate mainstem spawning.
5. Migrating and movement patterns observed through this study were combined with the results of gear experts that visited the system in 2005. Together, they suggest the following gear and location combinations be used to collect broodstock:
    a. tangle net at the confluence of the Okanogan and Columbia Rivers
    b. tangle net in the Okanogan River near the town of Omak.
    c. beach seine in the Similkameen River
    d. stationary trap at the confluence of the Okanogan and Columbia Rivers or above the confluence, near the trout hatchery
    e. fishwheel in the Okanogan River as described by Smith (2006)
    f. sport fishing at the confluence of the Okanogan and Columbia Rivers or in the town of Omak may also be suitable
    g. dipnetting in the Similkameen River pools would likely be successful but fishers experienced in this technique are difficult to find
6. The uppermost detection location and the average length of fish did not differ significantly by capture and release location (east or west ladders at Wells Dam) or origin (hatchery or wild as evidenced by clipped or unclipped adipose fin).
7. Genetic analyses were not done because they were not funded by this study. However, samples were collected and we recommend DNA microsatellite analysis be done to evaluate potential differences between the Similkameen, upper Okanogan, lower Okanogan, and mainstem Columbia migrants.

8. Planned modifications to the flow at Chief Joseph Dam and the addition of spill deflectors may change holding patterns for Chinook and should be evaluated.
9. Scale analysis indicated that most study fish were four year old wild fish that had reared in rivers prior to migrating to the ocean. There were also a few fish that had reared for a year in the hatchery prior to migrating to the ocean and a few fish that had reared in the mainstem Columbia (reservoir reared) prior to migrating to the ocean.

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7. Appendix

Two additional tables are provided for further clarification of fixed and mobile detections by river section (Table 22) and cumulative fixed and mobile detections by week and section (Table 23). Roughly the first half of the fieldwork was focused on tagging fish while the second half was focused on mobile surveys, locating fish, and recovering tags. Raft, vehicle, and foot surveys were used to more thoroughly survey areas and to collect tags from carcasses.

Table 22. Count of individual fish detected by fixed and mobile receivers for river, river section for various metrics.

River	Upper destination (stream section)	No. with uppermost detection in stream section	River total (No. with uppermost detection in stream section)	No. caught in fisheries	River total (No. caught in fisheries)
Columbia	C-00	3	117	0	17
	C-01	3		0	
	C-02	3		0	
	C-03	6		2	
	C-04	10		0	
	C-05	92		15	
Methow	M-01	18	35	0	0
	M-02	9		0	
	M-03	8		0	
Okanogan	O-01	14	58	0	2
	O-02	36		2	
	O-03	8		0	
Similkameen	S-01	33	70	1	1
	S-02	18		0	
	S-03	19		0	
All	All	280	280	20	20

Table 23. Cumulative number of fish in each segment by study week based on the last known detection of each tag. Includes all detections, e.g. carcasses drifting downstream and unrecoverable tags. Note did not do a survey of S areas until week 11, so may have been fish there prior that are not shown. Shaded weeks denote consistent raft, vehicle, and foot surveys.

River Section	Study week																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
C-00	0	0	0	0	2	2	4	4	6	7	7	7	9	9	10	12	12	12	13	13	13	13
C-01	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7	7	7	7
C-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	3	5	5	7
C-03	5	12	17	23	41	51	39	15	9	9	9	11	9	9	14	16	17	17	16	16	24	25
C-04	1	3	9	20	19	20	29	32	31	34	35	45	48	49	43	52	45	47	47	52	49	46
C-05	7	11	15	17	19	22	37	26	25	26	30	26	26	22	24	22	28	25	29	23	19	19
M-01	1	4	5	4	7	7	3	6	8	12	11	14	18	18	19	17	19	20	20	20	20	19
M-02	0	0	0	1	1	1	4	4	4	3	4	4	3	6	7	7	8	8	7	7	7	7
M-03	0	0	0	2	2	2	5	5	5	5	5	5	7	7	7	7	7	7	8	8	8	8
O-01	0	6	7	7	6	6	9	13	20	19	25	18	19	16	18	17	17	17	17	16	15	15
O-02	0	0	1	2	4	4	19	52	66	78	73	40	44	49	42	44	38	38	39	44	44	46
O-03	0	0	0	0	0	0	0	0	0	0	1	1	1	8	9	9	10	11	11	11	11	11
S-01	0	0	0	0	0	0	0	0	0	0	2	17	17	17	40	41	51	51	51	46	46	46
S-02	0	0	0	0	0	0	0	0	0	0	0	13	13	13	12	12	10	9	8	8	8	8
S-03	0	0	0	0	0	0	0	0	0	0	5	18	18	15	5	5	2	2	2	2	2	2
All	14	36	54	77	102	116	150	158	175	194	208	220	233	239	251	264	267	267	278	278	278	279