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FISH DIVISION

Oregon Department of Fish and Wildlife
Spring Chinook Salmon in the Willamette and Sandy Basins
Sandy River Basin Spring Chinook Salmon Spawning Surveys – 2012

Compliance Monitoring for Sandy Hatchery Biological Opinion – September 2013

ANNUAL PROGRESS REPORT

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KEY FINDINGS

1. The proportion of hatchery origin spawners (pHOS) for spring Chinook salmon *Oncorhynchus tschwytscha* in the Sandy River Basin was 24% in 2012, compared to the mean pHOS of 59% in 2008–2011.
2. Removing fin-clipped fish at weirs reduced pHOS from 45% to 24% in the Sandy River Basin.
3. Removing fin-clipped fish reduced pHOS upstream of the weirs from 41% to 12% in the upper Salmon River Basin, and 42% to 14% in the upper Zigzag River Basin. Areas upstream of the weirs accounted for 78% of the spawning in the upper Sandy River Basin.
4. Based on recovery of fin-clipped fish upstream of the weirs, we estimated that the percentage of fin-clipped fish passing uncounted above the weir (before weirs were installed or escaped passed the weirs) was 28% in the Salmon River Basin and 38% in the Zigzag River Basin.
5. The effect of weirs on spawning distribution was equivocal:
   a. At the small scale of weir locations, the percentage of wild fish spawning downstream of the weir in 2012 was higher than immediately upstream of weirs, but was low compared to the higher percentage of wild spawners in the primary areas in the upper basin.
   b. Spawning distribution among and within survey sections was highly variable. The percentage of wild fish spawning within a survey area ranged from a low of 14-15% in some areas to 33–48% in others.
   c. The distribution of wild spawners in the Salmon and Zigzag rivers was similar in 2012 to that in 2002–2010 in the absence of weirs.
   d. Ratios of redd density in the lowermost sections to redd density upstream in 2012 were at or near the 2002–2010 median. Ratios of redd density in the lower Salmon to middle Salmon were variable and was higher in 2012 than the 2002–2010 interquartile (but within the 90^{th} percentile) indicating an increase in redd density in the lowermost section. In the Zigzag River Basin, the ratio of redd density in the lower river to the upper river was highly variable and the 2012 ratio was within the 2002–2010 interquartile.
6. Counts of live fish indicated larger numbers of adult salmon holding downstream of the weirs than upstream, particularly in the lower Salmon River. Counts remained high in the lower Salmon after the trap catch peaked suggesting a continued movement of fish from the Sandy River into early October.
7. We found no evidence that operation of weirs delayed spawning. Date of first and peak spawning was similar or earlier in 2012 to previous years, with the exception that peak spawning in the uppermost section of the Salmon River upstream was later than the 2002–2010 mean.
8. Pre-spawning mortality of wild fish in the Salmon and Zigzag River basins was lower in 2012 than in 2003–2010 in the absence of weirs. Pre-spawning mortality was lower for wild fish than for hatchery fish

The estimated number of wild spring Chinook salmon in the upper Sandy River Basin in 2012 was higher than in the previous 10 years: 2.3 times higher than in 2002–2007 when fin-clipped fish were removed at Marmot Dam, and about two times higher than in 2008–2011. The estimated number of hatchery fish in the upper basin was about 60% lower than in 2008–2011.

BACKGROUND AND INTRODUCTION

Sandy River Basin

The Sandy River begins on the slopes of Mount Hood and flows 56 mi (90 km) to the its confluence with the Columbia River (Figure 1). Major tributaries include the Zigzag and Salmon rivers in the upper basin (Figure 2) and the Bull Run River in the lower basin (Figure 1). The glacial origins of the Sandy (Reid Glacier) and Zigzag (Zigzag Glacier) rivers results in the presence of suspended sediment in summer and fall when the glaciers melt, and large-scale movement of bedload material during winter rains. Starting about 2,000 years ago, several eruptive events on Mount Hood resulted in pyroclastic flows and lahars that flowed down the Sandy and Zigzag rivers and filled river valleys with deposits (Cameron and Pringle 1986). Unconsolidated sediment in the area known as Old Maid Flat is hundreds of feet deep (Pierson et al. 2011). The Old Maid eruptive period during the late eighteenth century, produced large amounts of sediment in the headwater canyons that was later flushed downstream the length of the Sandy River by a lahar and winter floods (Pierson et al. 2011). Descriptions of the Sandy River by Lewis and Clark in 1805 and 1806, about two decades after the major eruptive period, indicate the river was still aggrading from the reservoir of sediment deposits in the upper watershed (O'Connor 2004). Sediment deposits at the mouth of the Sandy had narrowed the Columbia River to between a one-quarter and one-half mile (compared to the present width of about one mile), and the river at the delta was described as shallow, laden with sediment, with a quicksand bottom (O'Connor 2004). Following the Old Maid eruptive period, aggradation was rapid and resulted in channel widening and braiding, which was followed by a slow degradation of the channel that took more than 50 years to reach the present bed elevation, at least three meters above the previous level (Pierson et al. 2011). This geologic and volcanic legacy has resulted in a highly dynamic ecosystem in which the upper Sandy and Zigzag rivers are prone to channel changes and lateral migration during winter floods, such as in 2009 and 2011 (English et al. 2011; English 2013).

Spring Chinook Salmon

Chinook salmon *Oncorhynchus tschawytscha* in the Sandy River Basin have been influenced by the dynamic landscape of the basin as described above, and by human activities. Rivers such as the Bull Run and the Salmon, and small streams such as Still Creek likely provided refugia for salmon during and after the major eruptive periods. However, population size may have fluctuated widely because of the large-scale changes in the watershed resulting from volcanic events and the subsequent input of sediment during floods. The historic size of the spring Chinook salmon population in the Sandy River Basin is unknown but was estimated to be at least 8,000–10,000 fish (Mattson 1955). Of these an estimated 5,000 were estimated to have spawned in the upper Bull Run River Basin.

Human Factors Affecting Spring Chinook Salmon

In addition to natural forces, spring Chinook salmon in the Sandy River Basin have been influenced by many anthropogenic factors for over a century (Taylor 1998), which resulted not only in a decline in the population but also likely influenced their long-term adaptation and natural selection. Among the factors were construction of fish racks to trap adult salmon and collect eggs, construction of dams, diversion of water from the river channels, overharvest by commercial fisheries, timber harvest and associated road building, and an expanded hatchery fish program in the 1970s and 1980s.

The first collection of spring Chinook eggs in the Sandy River Basin was in 1893. Because eggs were collected 6 Oct–6 Nov on the Sandy River, these were likely fall Chinook (Hubbard 1893). The first hatchery was built in 1898 on the lower Salmon River near Boulder Creek (Hubbard 1898). Racks were built across the stream channel to trap and collect adult salmon for spawning. Many of the eggs collected in the Sandy River basin were shipped out of the basin and the hatched fry were put into other rivers (Craig and Suomela 1940).

Access to the upper Bull Run Basin was blocked by the construction of a dam in 1922, resulting in the loss of an estimated run of 5,000 spring Chinook salmon (Mattson 1955). A second dam was built on the Bull Run River in 1929, and the two dams were used to divert water to the city of Portland. In 1912, the Sandy River-Bull Run hydroelectric complex was completed, which included dams on the Sandy River (Marmot Dam) and on the Little Sandy River. Sandy River water was diverted through a tunnel to the Little Sandy River at the Little Sandy dam site, and from there the water flowed through a wooden flume to Roslyn Lake, an artificial lake that acted as a penstock for the powerhouse downslope on the Bull Run River. Although Marmot Dam included a wooden fishway, flood damage to the fishway resulted in little or no passage from 1912–1918. The fishway was improved in 1926 in an attempt to increase fish passage over the dam. Additional attempts to improve adult fish passage at the dam continued after 1955 when the fishway was rebuilt several times. In 1989, the timber crib dam was rebuilt with a new fishway.

The diversion canal to the Little Sandy River and Bull Run powerhouse was not screened until 1951, which resulted in a high loss of juvenile salmon and steelhead (Craig and Suomela 1940), and inadequate velocities or blockage of ports by silt often resulted in poor passage efficiency (Leonards 1960; Hansen 1976). Downstream of Marmot Dam, the Sandy River was often reduced to isolated pools in summer and fall, resulting in poor upstream passage and attraction to the fishway (*see* Figure 3). Minimum stream flow to provide passage for adult fish and to increase rearing area for juvenile fish was not established for the Sandy River downstream of the dam until 1974. In addition, salmon and steelhead were falsely attracted to the Bull Run River because of the diversion of Sandy River water. After construction of the Bull Run dams, spring Chinook salmon were confined to the lower 6 miles of river, which had poor spawning conditions because of low flow and limited gravel.

Although the objective of the early hatchery programs was to increase the population of returning adults, the overall effect appeared to be minimal for many reasons. Hatchery practices not only had a direct effect on the population through collection of eggs, but the state of fish culture at the time was not adequate for treating disease in juveniles or achieving a large size in juvenile fish, which was later shown to increase survival and adult return rates. In addition, the cumulative effects of the dams, water diversions, development in the basin, and harvest of spring Chinook in the Columbia River also resulted in a decrease in the wild Chinook population. As a result, the Sandy River population of spring Chinook salmon had declined drastically by the 1950s and 1960s, and was described as "*rare*" (Leonards 1960) or "*remnant run*" (Hansen 1976). For example, the count of spring Chinook salmon at Marmot Dam was 5, 0, and 10 adults in 1955, 1956, and 1957, respectively (ODFW 2002). From 1960 to 1970, the median annual count at

Marmot Dam was 63 adult spring Chinook salmon, and was as low as 13 fish in 1965 (ODFW 2002).

Egg collections and hatchery operations continued periodically in the upper basin until 1912, after which these operations were relocated to Marmot Dam. Racks were often constructed immediately downstream of Marmot Dam or fish were collected in the fishway (Craig and Suomela 1940), and millions of eggs were collected from 1913 to 1955. Available records indicate there was no hatchery activity in the Sandy River Basin from 1926 through 1937, but salmon fry from Bonneville Hatchery were released in the basin in 1933–1936 (Craig and Suomela 1940). A small hatchery was operated immediately downstream of Marmot Dam from 1938 to 1948, the last year only for egg collection (Wallis 1966). Information in Craig and Suomela (1940) suggests that for some years no anadromous fish were passed into the upper basin: "*The unscreened Marmot diversion makes it inadvisable to permit* [spring Chinook salmon and steelhead*] to go into this area [*upper Sandy and Zigzag rivers*] at this time.…continue operation of [*the*] hatchery at Marmot and liberate the fish below the dam since this saves the loss of young fish in the Marmot diversion, which would occur if natural spawning were allowed above Marmot Dam*. This practice may have continued until the diversion canal was screened in 1951. The Sandy Hatchery on Cedar Creek opened in 1951.

Initially, spring Chinook salmon released in the Sandy River Basin were derived from the local population, although use of Willamette and McKenzie stocks was recorded in the 1938, 1941–1942, and 1957 brood years (ODFW 1997). Beginning with the 1972 brood year, the Willamette Hatchery stock of spring Chinook salmon was released in the Sandy River Basin, with many of the early release sites located upstream of Marmot Dam (Salmon River, Still Creek, and upper Sandy River). Spring Chinook salmon from Carson Hatchery stock (Washington) were released in 1977 and 1978 (ODFW 2002). Large increases in the number of adult Chinook returning to the basin in the late 1970s through 1990s were attributed to an increase in the number of hatchery fish released in the basin and advancement of fish culture practices. However, most of the returning adults were likely progeny of hatchery fish and little was known about the state of the wild fish populations. Release of hatchery fish in the upper Sandy River Basin continued until 1994. A portion of the hatchery release was acclimated in ponds just downstream of Marmot Dam in 1993–1997. Beginning with the 2002 brood year, a new hatchery stock was started with unclipped fish collected at Marmot Dam.

Spawning Habitat of Spring Chinook Salmon

Spring Chinook salmon generally spawn in the upper reaches of watersheds because they enter freshwater early and can migrate to the upper watershed areas during high flow in spring and early summer (Healey 1991). Because spring Chinook salmon must hold in rivers for several months before spawning, streams in the upper watershed provide better holding conditions, such as low water temperatures, than streams in the lower watershed. The historic and specific distribution of spring Chinook salmon in the Sandy River Basin is largely unknown prior to the completion of the Sandy hydroelectric project. However, some records provide information about the general spawning distribution of spring Chinook salmon.

Bull Run River Basin

The upper Bull Run River Basin was blocked to anadromous fish at RM 5.9 by a diversion dam (Headworks Dam) completed in 1921 (CoPWB 2008), which resulted in the loss of approximately 37 miles of salmon and steelhead habitat (Taylor 1998). A rock spillway weir was completed in 1965, which is the present upper limit for anadromous fish at RM 5.8 (CoPWB 2008). These dams are part of the water supply system for Portland, Oregon, which also includes Dam #1 at RM 11.1 (1929) and Dam #2 at RM 6.2 (1962). The productive capacity of the lower 6 miles is limited because the quantity of spawning gravel is small and streamflow has been reduced. Mattson (1955) noted "*…the spawning areas were located above the present-day dams…" and further noted "the available 6 miles remaining is of very little value to salmon due to the lack of spawning areas and greatly reduced stream flows.*" Craig and Suomela (1940) characterized the lower Bull Run as "*…composed largely of bedrock and boulders, spawning areas are restricted to small, scattered 'pockets'.*"

Sandy River Basin

Specific information about the spawning distribution of spring Chinook salmon is not available prior to the completion of Sandy hydroelectric project. Once the project was completed, the upstream migration and subsequent spawning distribution of spawning spring Chinook salmon was altered because of impaired upstream migration from reduced flow, false attraction of fish into the Bull Run River from diversion of Sandy River water into the Bull Run River, and impaired passage of fish into the upper watershed from inadequate adult fish passage facilities at Marmot Dam. Based on accounts from residents familiar with the basin prior to Marmot Dam, Mattson (1955) reported that spring Chinook salmon were once abundant in the Sandy, Salmon, and Zigzag rivers.

Mattson (1955) characterized the Salmon River as "*the most potentially productive area within the entire Sandy River with regard to spring chinooks, silvers, and steelhead.*" Egg take records from the Salmon River Hatchery at Boulder Creek suggest the Salmon River was a major producer of spring Chinook salmon. For example, over 3.5 million eggs were collected from 766 females from July 14–August 29, 1903 (VanDusen 1905), which represents a minimum estimate of 1,532 fish at a 1:1 sex ratio. However, this number would not include the harvest effect of large commercial fisheries in the Columbia River at the time. In addition, the egg collection number does not include spawners downstream of the rack (approximately 1 mi) or the escapement of salmon past the racks. A small dam was built in 1904 on the Salmon River upstream of the hatchery to replace the wooden racks and increase capture efficiency. The dam was equipped with a fishway to trap fish for eggs and to provide passage for fish not needed (VanDusen 1905). By 1910, the number of fish reaching the Salmon River and subsequent eggs takes had declined, which was thought to be because large amounts of sediment and debris blocked the main channel of the Sandy River at the mouth and prevented salmon from entering the river in sufficient numbers, in addition to the effects of a large number of saw mills and logging camps in the basin (Clanton 1911; McAllister 1911). Holding spring Chinook salmon in the river with racks presented other problems as noted in an early report of operations (Hubbard 1899):

> "*The rack was built in early June, before any salmon ascended the stream, and in the first part of the summer the prospects for a good season's work seemed bright, as many salmon were observed in the pools below the rack.*

> *Before they were ready to spawn, however, many of them were killed and others injured by explosives used by people in the vicinity, so that very few eggs were secured.*"

The Zigzag River generally was not considered a large producer of spring Chinook salmon, but Still and Camp creeks were believed to be important. Although the use of the upper Sandy River for spring Chinook spawning was noted in early reports, we found no records of spawning surveys to document specific distribution. One report stated that identification of spawning area was "*…recorded from notes made during the fishery and from angler reports of fish being observed in the area.*" (Pirtle 1953). Such observations might indicate only that spring Chinook salmon were migrating or holding in areas of the mainstem Sandy River rather than spawning. Early surveys of the Sandy River noted the lack of spawning gravel upstream from the mouth of the Bull Run River. For example, Craig and Suomela (1940) note: "*Spawning areas in the 12-mile section to Marmot Dam are restricted by sand, boulders, and bedrock to small scattered 'pockets'.*" They also note the section from Marmot Dam to the Zigzag River confluence as "*…predominantly large rubble and boulders with an admixture of silt and sand. Wide flood washes are frequent and spawning areas are small and scattered.*" Pirtle (1953) also noted conditions of the upper Sandy River:

> "*…above Brightwood* [near mouth of Salmon River]*…to Truman Road* [Lolo Highway, near mouth of Zigzag River]. *The gradient remains steep and spawning gravel is confined to small pockets. The gradient above the Truman Road bridge* [near mouth of Zigzag River] *remains steep and the river in this section has a constant drop with mostly swift, tumbling water and an absence of large eddies and pools. The banks are of an unstable mixture of sand and gravel, which appears to shift and erode constantly.*"

Management and Spawning Surveys

All hatchery spring Chinook salmon in the Sandy River Basin were released with adipose fin clips and thermally marked otoliths beginning with the 1997 brood year. All fin-clipped hatchery spring Chinook salmon were trapped and removed at Marmot Dam in 2002–2007. After the removal of Marmot Dam in 2007, the percentage of hatchery-origin spawners (pHOS) in spring Chinook salmon increased in the upper Sandy River Basin, comprising 45–77% of the spawning population in 2008–2011, compared to a mean of 11% (4–18%) in 2002–2007. Although most of the returning hatchery fish were likely derived from local Sandy Chinook salmon collected at Marmot Dam, the high proportion of hatchery fish in the spawning population exceeded recovery plan goals and could reduce the long-term productivity of the Sandy River Basin spring Chinook salmon. Beginning in 2011, the Oregon Department of Fish and Wildlife (ODFW) implemented several measures to reduce the proportion of hatchery Chinook spawning in the wild including: 1) operation of weirs and traps in the lower Salmon and Zigzag rivers to remove hatchery fish, 2) reduction in the number of hatchery smolts released, and 3) acclimation of juvenile hatchery smolts in the Bull Run River with the objective of trapping and removing adults that home back to that river.

Spring Chinook salmon from the Sandy Basin were listed as threatened under the Endangered Species Act in 1999, along with other stocks of Chinook salmon from the lower

Columbia River (NOAA 1999). A Hatchery Genetics Management Plan (HGMP) for the Sandy River Basin was written in 2008, revised in 2011 and finalized in 2012 (ODFW 2011), and a subsequent Biological Opinion (BiOp) on the hatchery program in the Sandy River Basin was issued by National Marine Fisheries Service (NMFS) in September 2012 (NMFS 2012). These two documents provide performance standards, monitoring requirements, and terms and conditions for the hatchery program. Standards and measures listed in these two documents that are relevant to monitoring spring Chinook salmon include (referenced in italics):

1. Reduce stray of hatchery spring Chinook salmon in the upper Sandy River (above the confluence of the upper Sandy and Salmon rivers) through construction of off-station acclimation ponds, weirs/traps, and other stray reduction measures. *HGMP Performance Indicator (14)(a)*
2. Ensure that interactions on the spawning grounds with fish produced by the Sandy Hatchery…are kept to the lowest feasible levels. *BiOp RPA 2.9.3 (1)*
3. Performance standard for the pHOS (proportion of naturally spawning fish that are of hatchery-origin): 10% maximum for all locations in the Sandy Basin. ODFW will monitor the presence of hatchery fish on the spawning grounds to verify compliance with these standards. *BiOp Proposed Action 1.3.1 (Adult Management), BiOp Amount or Extent of Take 2.9.1 (2), and HGMP Performance Indicator (5)(b)*
4. ODFW shall conduct surveys, annually, to determine the timing, abundance, and distribution of Sandy Hatchery spring Chinook…that spawn naturally. *BiOp Terms and Conditions 2.9.4 (1a)*
5. Complete census, throughout the Sandy Basin, of the location, number, and timing of naturally spawning hatchery fish. *BiOp Proposed Action 1.3.1 (RM&E)*
6. Life history characteristics of hatchery origin and wild spring Chinook salmon will be monitored through analysis of hatchery returns (run timing and age composition), spawning ground surveys, and juvenile outmigrants. *HGMP Performance Standard (6)*
7. Maintain genetic and ecological characteristics of wild population. Corvallis Research along with local District staff currently conduct annual spawning surveys throughout the basin to determine distribution and spawning success. *HGMP Performance Standard (14)*
8. Maintain the current productivity of the wild, naturally spawning population. Conduct spawning ground surveys to quantify redd and spawner abundance. *HGMP Performance Standard (15)*
9. Ensure that take resulting from the operation of weirs in the Sandy Basin is inconsequential. *BiOp RPA 2.9.3 (3)*
10. Weir/trap operation in the upper Sandy River Basin and Sandy Hatchery operations do not result in significant stress, injury, or mortality to naturally produced salmonid populations. *HGMP Performance Indicator (12)(a)*
11. The surrogate take indicator [for operation of weirs] is any change greater than 20 percent in spawning distribution above and below the weirs and in pre-spawning mortality from what was measured during previous spawning ground surveys prior to the installation and operation of the weirs in 2011. *BiOp Amount or Extent of Take 2.9.1 (4)*
12. ODFW, as part of the spring Chinook salmon spawning ground surveys, will annually monitor and report changes in spawning distribution and estimate pre-spawning mortality. *BiOp Amount or Extent of Take 2.9.1 (4)*

This report summarizes data we collected during spawning surveys in 2012 to assess the following primary aspects of the hatchery program pertaining to spring Chinook salmon:

1. Hatchery and wild composition of the spawning population,
2. Effect of operating weirs in the Salmon and Zigzag rivers on spawning distribution of naturally produced spring Chinook salmon,
3. Effect of operating weirs on pre-spawning mortality of naturally produced fish.

The surrogate indicator of change in spawning distribution from previous years is not possible at the specific scale of weir locations because our surveys in previous years used different section breaks. This report assesses spawning distribution change at the scale of previous section breaks.

We also report on distribution and abundance of naturally produced spring Chinook salmon in the upper Sandy River Basin. Other measures and standards such as age composition are long-term metrics, and although data are compiled and summarized (Appendix Tables 4–5), analyses about effect of the hatchery program will be conducted in the future to assess effects and changes in the Sandy Hatchery program. Assessment of productivity in the upper Sandy River Basin will be at a multi-year scale, in which brood year returns and adult-to-adult survivals will be derived from age composition data and estimates of returns.

METHODS

Surveys

Spring Chinook spawning surveys in the Sandy Basin consist of redd counts and carcass recovery using standard survey protocols (e.g., Crawford et al. 2007; Gallagher et al. 2007). We designed these surveys to be a complete census of the primary spawning areas for spring Chinook salmon in the upper Sandy River Basin. Based on our surveys and other information, we compiled a list of rivers, river sections, and streams in the Sandy River Basin with spawning potential for spring Chinook salmon, and an assessment of habitat quality (Appendix Table 1). All observed carcasses are collected during the surveys, although surveyors are unable to retrieve all carcasses because of factors such as deep water (Crawford et al. 2007). Surveys are spatially continuous within the areas known to support spring Chinook salmon spawning, including areas where little or no spawning by spring Chinook salmon has been documented. A census survey does not provide a complete count of all redds in a basin because of environmental factors such as high flow events that can reduce water clarity. However, we generally obtain good redd counts before the onset of steady fall rains that can affect visibility for long periods. Usually the first fall rains cause a brief increase in stream flow that then decreases to allow continued surveys. Glacial sediment and reduced visibility are factors in the Sandy and Zigzag rivers that can affect the ability to survey for redds. Poor visibility in the glacial Zigzag River can affect our ability to count redds or to locate and recover salmon carcasses, the degree of which is variable within and among survey years. Because the mainstem Sandy River is a predominantly glacial river, limited water visibility from glacial melt or fall rains, constrain our ability to survey the river. Therefore, we have surveyed the Sandy River with less intensity and consistency than other areas, and the quality of the survey data is dependent on water clarity. However, in years when the Sandy River has been surveyed, over 90% of the redds were found in the areas that have been regularly surveyed since 1996.

Streams are segmented into survey sections based on geographical landmarks such as bridge crossings or campgrounds (Figure 2), and we have surveyed the same sections since 1996. In 2012, we divided the lower sections of the Salmon and Zigzag rivers into two subsections upstream and downstream of weirs to allow additional analyses of the potential effect of trapping on distribution of spawners and pre-spawning mortality. Following the removal of Marmot Dam in 2007, the Little Sandy River has been included in our survey area when water conditions have permitted sampling. In addition, we have coordinated with City of Portland Water Bureau (CoPWB) biologists on surveys of the lower Bull Run River.

We conduct surveys on a scheduled rotation to ensure full coverage of the basin. In 2012, the objective of the rotational schedule was to survey the highest priority areas once per week and survey the secondary areas once every two weeks. In 2012, we also mapped redds using a global positioning system (GPS), although equipment failures resulted in some gaps in the mapping data.

Redd Counts

Redd counts are used to estimate spawner escapement and run size of spring Chinook salmon, spawning distribution within the Sandy River Basin, and spawning distribution relative to operation of weirs and traps. We surveyed all spring Chinook salmon spawning areas in the upper Sandy River Basin on a 7–10 day cycle, with increased effort during peak spawning to ensure weekly coverage of the primary spawning areas that have accounted for 80–90% of all redds in the upper basin (Salmon and Zigzag rivers, and Still Creek). All redds are counted in each survey and usually sections are surveyed by the same people throughout the spawning season. Surveyors are trained to recognize the physical characteristics of completed redds such as the excavated pit and the tailout mound, which are used to identify individual redds in areas where multiple redds may be present. These techniques allow surveyors to track spawning activity as the season progresses and to identify new redds in heavily used gravel patches. In addition, experienced staff will repeat surveys on the same day that redds were counted by other surveyors, at intervals throughout the spawning season. These surveys help train less experienced personnel and verify peak redd counts.

Redds were tallied on a personal digital assistant (PDA) and coordinates were recorded with a global positioning system (GPS) unit connected to the PDA. Surveyors recorded comments on the PDA to help interpret data at the end of the season. We had a shortage of PDAs in 2012 because of equipment failure and were therefore unable to map redds for all spawning areas or were unable to collect redd locations during peak spawning for all areas. Redd counts are summarized by sections that have been used since 1996. In 2012, we split the lower sections of the Salmon and Zigzag rivers based on the location of weirs to evaluate potential effects.

Carcass Recovery

The information we collect from spring Chinook salmon carcasses include pre-spawning mortality, hatchery:wild composition of the spawning population, and age composition and freshwater life history in wild fish. We processed all recovered carcasses and the specific data collected depends on the condition of the fish and fin clip status. We removed the tail of a processed carcass at the caudal peduncle to identify fish that were sampled, and returned the carcass to the stream channel. Carcasses were counted as unprocessed if they were decomposed and could not be identified as being previously processed, or if they were too decomposed to assess the presence or absence of a fin clip. We processed all recovered spring Chinook salmon carcasses for which we could identify definite fin clip status or questionable fin clip status (e.g., partially clipped).

Surveyors cut open the processed carcasses to verify sex. We determined spawning success based on the retention of eggs in female salmon. We scanned all fin-clipped fish with a hand-held detector to check for coded wire tags (CWT), and we collected the snout and biological data (fork length, sex, spawning success) from those with a tag. Snouts were put into a plastic bag and a waterproof tab with a unique identification number was placed in the bag. Surveyors entered all data into PDAs including snout identification number and biological data. We collected otoliths from all carcasses with an intact adipose fin (and with questionable fin clips). We also collected scales and tissue samples from all unclipped fish. Otoliths were put in individually numbered vials, and scales were put in numbered waterproof envelopes. Data were recorded on the scale envelopes and entered in a PDA form including a cross-reference to the otolith and tissue vial numbers. Other biological information entered in a PDA included fork length (cm), sex, spawning success, and location.

Trapping

ODFW District biologists installed weirs in the lower Salmon and Zigzag rivers to trap and remove fin-clipped Chinook salmon (Figure 2). We incorporated additional metrics in our surveys to monitor the potential effect of weirs and traps on the spawning distribution and mortality including:

1. Identified weir locations in our standard survey sections to monitor counts upstream and downstream of the weirs
2. Recorded live fish, carcasses, pre-spawning mortality, hatchery:wild composition, and redds upstream and downstream of weirs
3. Analyses included:
    a. hatchery:wild composition of spawning population upstream and downstream of weirs, and within the upper Sandy River Basin
    b. comparison of proportion of hatchery spawners among years
    c. distribution of redds within Salmon and Zigzag River Basins and within the upper Sandy River Basin
    d. distribution and timing of live fish relative to weir locations
    e. timing of passage and spawning compared to previous years
    f. pre-spawning mortality within watersheds and in the upper Sandy River Basin

Data Management and Analysis

We recorded all data for carcasses and redds in PDA forms and uploaded data daily to computers. Data checks were conducted in-season and at the end of the season to identify and correct data entry errors or to verify questionable data. We summarized data by section, including new subsection breaks at the weirs in the lowermost sections of the Salmon and Zigzag rivers. We periodically reviewed our survey frequency among sections to determine the need for additional redd counts or carcass collection within certain sections.

Snouts collected from spring Chinook salmon were delivered to the ODFW tag processing lab in Clackamas and biological data associated with the sample were tabulated in a spreadsheet and sent to data processors at the ODFW Headquarters in Salem. All biological samples (otoliths, scales, tissues) were cataloged and either stored at the Corvallis Research Lab or analyzed. Otoliths were analyzed by the Washington Department of Fish and Wildlife (WDFW) Otolith Lab in Olympia to identify the presence or absence of induced thermal marks. Scale samples and otolith samples were cross-referenced, and after otoliths were analyzed to identify wild fish, the scales from wild fish were analyzed to determine age composition and freshwater life history. Scale analysis was conducted at the Corvallis Research Lab by the Fish Life History Analysis Project. Tissue samples are currently stored for genetic studies of spring and fall Chinook salmon composition pending available funding. Priority of analysis will be for samples collected in the Bull Run and lower Sandy rivers to distinguish run type (spring or fall). Samples collected in the Sandy River Basin may also provide the basis of future studies on the rate and magnitude of genetic change in a population where hatchery fish are successfully excluded.

Composition of Spawning Population

We used carcass sampling to identify hatchery and wild fish. Otoliths were analyzed to apportion the unclipped or unknown fish (with a partial adipose fin clip or with an indeterminate fin clip status) into wild and hatchery categories. Banding patterns are induced in the otoliths of all hatchery spring Chinook during incubation by raising or lowering the water temperature on a set schedule, which results in increases or decreases in the growth rings of otoliths and creates a pattern that can be used to differentiate between hatchery and wild fish (Volk et al. 1999).

We estimated s pHOS from the number of known fin-clipped carcasses recovered and the number of carcasses that have thermally marked otoliths. Because of differences in size of rivers and streams and because of physical differences such as gradient and water clarity, the efficiency of recovering carcasses can vary among rivers and survey sections. A factor based on the distribution of redds was used to correct for potential bias in the collection of carcasses that might affect the estimated composition of the spawning population. The spatial distribution of carcasses was compared to the spatial distribution of redds as an unbiased measure of spawning distribution, and carcass numbers was adjusted if the carcass distribution was significantly different than the redd distribution (Chi-square test on frequencies). Composition of the spawning population was estimated for survey sections, subbasins, and the Sandy River Basin.

We evaluated the effectiveness of traps by comparing the observed pHOS to the assumed pHOS if hatchery fish had not been removed at the weirs. We also estimated the magnitude of pHOS reductions upstream of the weirs in the Salmon and Zigzag rivers, and the relative proportion of the Sandy River Basin population that benefits from trapping and removing hatchery fish at the weirs.

Distribution of Spawning Population and Trapping

We evaluated the potential effect of weirs and traps on the spawning distribution of spring Chinook salmon in context of the BiOp performance standards. In conjunction with the ODFW District biologists, we collected and analyzed the following data:

1. Distribution of hatchery and wild origin carcasses relative to weir locations
2. Distribution of redds within Salmon River and Zigzag River basins and within the upper Sandy River Basin
3. Counts of live fish relative to weir locations and relative to passage timing at the weirs

4. Timing of adult fish through the weirs
5. Timing of spawning (first date and peak date) upstream and downstream of the weirs

The surrogate indicator of change in spawning distribution from previous years as outlined in the BiOp could not be used at the specific scale of weir locations because our surveys in previous years used different section breaks. In 2012, we assessed alternative methods of assessing the potential effect of weirs on spawning distribution such as distribution among areas of the Salmon and Zigzag River basins and ratio analysis of redd densities within the basins.

Although we could not assess the effect of weir operations in the immediate vicinity of the weirs, we assessed the relative effect of weirs by analyzing spawning distributions among areas within the Sandy and Zigzag River basins. We summarized the spawning distribution of wild spring Chinook salmon for three sections within the Salmon and Zigzag River basins for 2002–2010 in the absence of weirs and compared them to the 2012 distribution when weirs were operated. We tested for differences in the spatial distribution of spawning within each basin with a one-way ANOVA with Holm-Sidak tests for post hoc comparisons. We calculated a ratio of redd density in the lower area of the Salmon and Zigzag rivers that encompassed the location of the weirs to redd density in areas upstream, and compared the 2012 ratios to 2002–2010 values. Ratios $\geq$ 1.0 indicate a higher redd density in the lowermost section compared to sections upstream. We also used specific redd location data collected in the late 1990s to estimate the distribution of redds downstream of the 2012 weir sites, and compared the distribution to that in 2012. We used data in years when redds were mapped during peak spawning and when surveys were complete for all sections: 1998 for Salmon River Basin and 1997 for Zigzag River Basin.

We used counts of live fish in our weekly surveys, counts of live fish by District biologists in the immediate vicinity downstream of the weirs, and counts of fish at the weirs to assess passage timing of adult spring Chinook salmon in the Salmon and Zigzag rivers. We assessed the general timing of spawning for spring Chinook salmon in the upper Sandy River Basin with dates of first redds observed and peak redd counts. For date of first spawning we did not include years when surveys began late and numerous redds had already been conducted. However, we included those years for estimating the date of peak spawning. For peak spawning, we did not include years when only one survey or no late surveys were conducted, and we compared 2012 to the mean and range for 2002–2010.

Pre-Spawning Mortality and Trapping

We estimated pre-spawning mortality by examining female carcasses for retention of eggs. If a recovered female had most of her eggs left in the body cavity then the fish was categorized as a pre-spawning mortality. Because male salmon can spawn with more than one female and their testes often remain intact, it is difficult to determine pre-spawning mortality for male fish.

We used pre-spawning mortality of wild adult spring Chinook salmon in 2003–2009 as the baseline to assess potential effects of weirs on mortality. We did not use 2002 or 2010 for all areas (or 2003 in the Zigzag River Basin) because our spawning surveys did not begin until mid-September, which reduced the probability of recovering pre-spawning mortalities. We also compared the annual variation of pre-spawning mortality in the upper Sandy River Basin to that in the upper Clackamas River and McKenzie River basins. Fin-clipped spring Chinook salmon have been excluded from the upper Clackamas River Basin since 2002 and the upper McKenzie River Basin supports the largest run of wild spring Chinook salmon in the upper Willamette River Basin.

Abundance and Distribution of Naturally Produced Salmon

Direct counts of spring Chinook salmon for the upper Sandy River Basin have not been available since removal of Marmot Dam in November 2007. We currently use two methods to estimate run size in the upper Sandy River Basin (note that these methods are not independent because they use the same data):

1. Linear regression of Marmot Dam count to redds counted upstream of the dam from 1996–1998 (early surveys) and 2002–2006 (Figure 4). We did not conduct a complete survey in 1999 and did not survey the basin in 2000–2001. We did not include 2007 because of unknown effects of dam deconstruction, operation of a temporary weir, and additional handling of Chinook salmon in a trap-and-haul operation to move fish upstream of the cofferdam.
2. When the number of redds is beyond the range used to develop the regression, we estimated the number of adult Chinook salmon based on the average fish:redd ratio in 1996–1998 and 2002–2006 (from dam counts and redds counted upstream of the old dam site), and the number of redds counted in the upper basin after removal of the dam.

We used weir counts of spring Chinook salmon and redds upstream of the weirs to estimate escapement in the upper Salmon and Zigzag River basins. Carcasses recovered upstream of the weirs were used to apportion the escapement into unclipped and fin-clipped fish.

RESULTS

We conducted spawning surveys for spring Chinook salmon in the Sandy River Basin August 22–October 30. Surveys of the primary spawning areas in the Salmon and Zigzag River Basins occurred 6–9 times through the season, generally on a weekly rotation. Secondary spawning areas in the upper Zigzag River and Lost, Clear Fork, Devil’s Canyon, Cheeney, and Boulder creeks were surveyed 1–5 times. We were unable to survey the Sandy River upstream of the Marmot Dam site in 2012 because of poor water clarity from glacial sediment. We did not survey the Little Sandy River in 2012 because of high water and poor visibility during the period of peak spawning, but CoPWB biologists conducted a survey in early November. The Bull Run River was surveyed by CoPWB biologists.

Composition of Spawning Population

The estimate of pHOS in the Sandy River Basin in 2012, including the Bull Run River and adjusted for bias in recovery of carcasses, was 24.0% (unadjusted 25.1%). This compares to a mean pHOS of 59% in the Sandy River Basin in 2008–2011. For the upper Sandy River Basin (upstream of the Marmot Dam site), the estimated pHOS in 2012 was 23.7% when adjusted for carcass recovery bias and 25.0% without adjustment. This compares to a mean pHOS of 61% in the upper basin in 2008–2011 after the removal of Marmot Dam, and a mean of 11% in 2002–2007 when fin-clipped fish were sorted and removed at the dam (Figure 5). About 21% of the spring Chinook salmon recovered in the spawning streams of the upper Sandy River Basin in 2012 were fin-clipped (Table 1). Excluding carcasses that died prior to spawning, pHOS would decrease by 2% because pre-spawning mortality was higher in hatchery fish than in wild fish (*see* **Effect on Pre-spawning Mortality**).

The percentage of hatchery origin spawners was lowest in the Salmon and Zigzag rivers and highest in Lost and Clear Fork creeks (Table 2). The percentage of hatchery spawners in 2012 was 12% and 14% upstream of weirs in the Salmon and Zigzag rivers, respectively, whereas over 50% of the spawners downstream of the weirs were hatchery origin (Table 2).

Trapping

Effect on Composition of Spawners

District biologists from ODFW installed weirs and fish traps in the lower Salmon and Zigzag rivers to capture and remove hatchery Chinook salmon migrating to spawning areas. Trapping began June 18 in the Salmon River and July 4 in the Zigzag River (Table 3). Flow in the Zigzag River was too high to install the weir prior to July 4. Traps were checked once a day in the early part of the season, and trapped fish were passed upstream if they did not have a fin clip or were removed and transported to Sandy Hatchery if they were fin-clipped. Beginning September 11, traps were monitored throughout the evening and night to process fish more frequently.

Over 400 hatchery Chinook salmon were removed at the traps in 2012 and 1,540 unclipped fish were trapped and passed upstream (Table 3, Figure 6). We estimated that removing fin-clipped fish at the traps reduced pHOS in the upper Sandy River Basin from 44.3 to 23.7% (Table 4, Figure 7). Although pHOS in the upper Sandy River Basin remained above the minimum objective of 10%, upstream of the weirs pHOS was reduced to 12.1% and 14.4% in the Salmon and Zigzag River basins, respectively (Table 2). Spawning in these areas represented 78% of all spawning in the upper Sandy River Basin in 2012.

In 2012, the distribution of hatchery spring Chinook salmon was similar among the Salmon, Zigzag, and two upper Sandy River tributaries, and within the Salmon and Zigzag River Basins (Figure 8). However, the distribution of wild origin spawners was skewed toward the upper Salmon and Zigzag River basins, which was partially because of the removal of fin-clipped fish at traps, but also because these upper areas were where spawning activity was highest (Figures 8 and 9). Since surveys began in 1996, redds in the upper Salmon and Zigzag River basins have represented > 75% of all redds in the upper Sandy River Basin, and has been as high as 91%.

The presence of fin-clipped adult Chinook salmon upstream of the weirs indicates fish migrated upstream when weirs were not in place (prior to installation or after removal), fish escaped through the weirs, or a combination. We found five fin-clipped fish in the upper Salmon River after the weir was removed on October 14, but four of those were found on October 15 in the uppermost section and were unlikely to have migrated to the area, spawned, and died in one day. One fin-clipped fish was found in the uppermost section on October 23 and could have moved upstream after the weir was removed. In the Zigzag River Basin upstream of the weir, we found no fin-clipped fish during surveys done after the weir was removed. These data indicate that most fin-clipped fish likely migrated into the upper watersheds prior to installation of the weirs or were able to pass through them.

We estimated the percentage of fish that migrated prior to installation of the weirs or that escaped through the weirs by assuming 3.0 fish/redd based on studies in Oregon and Idaho (Lindsay et al. 1989; Lofy and McLean 1995; Faurot and Kucera 2003; Rabe et al. 2006; Tardy and Denny 2011). In the Salmon River, we estimated that 14% of the unclipped fish and 28% of the fin-clipped fish passed uncounted into the upper watershed (Table 5). The percentage of uncounted fish in the Zigzag River Basin was higher than the Salmon for unclipped (56%) and fin-clipped fish (38%). Alternatively, these estimates suggest that 72% of the fin-clipped fish were removed in the Salmon River Basin compared to 62% in the Zigzag River Basin. The Zigzag River weir was installed over two weeks later than the Salmon River trap. In addition, adult Chinook salmon may have occasionally escaped through the Zigzag weir because the glacial substrate is less stable than the substrate in the Salmon River, making it more difficult to prevent holes from forming underneath the weir.

Effect on Distribution of Spawners

Directly assessing changes in spawning distribution in 2012 relative to weir locations as a potential effect of operating weirs was not possible because we did not collect data at the weir-specific scale in previous years. Therefore, we used other measures to assess the potential effect of operating weirs in the lower Salmon and Zigzag rivers on distribution of spawners upstream and downstream of the weirs.

Within the Salmon and Zigzag river basins, the largest number of spring Chinook salmon spawned in the upper Salmon River and Still Creek, respectively (Figure 9). At the small geographic scale of the weir break, the number of wild spawners was higher downstream of the weirs than immediately upstream of the weirs, but was much lower than the number of wild spawners in the primary areas upstream (Figure 9). The distribution of spawning by wild spring Chinook salmon in the Salmon and Zigzag river basins was variable in 2002–2010 within and among sections (Figure 10). Within the Salmon River Basin, the range in the percentage of spawning was greater in the upper (41%) and lower (48%) areas than in the middle area (15%). In the Zigzag River Basin, the percentage of spawning was more variable in Still Creek (41% range) and the lower Zigzag River (33%) than in the Zigzag River upstream of Still Creek (14%).

Within each of the basins, the distribution of wild spawners was significantly higher in the upper Salmon River (ANOVA: $F_{2,24} = 11.71$; $P < 0.001$) and in Still Creek (ANOVA: $F_{2,24} = 72.47$; $P < 0.001$) than in other areas of the basins (Figure 10). In 2012 when weirs were operated in the lower Salmon and Zigzag rivers, the distribution of spawning by wild fish was generally similar to that in 2002–2010 in the absence of weirs (Figure 10). The distribution of wild spawners in 2012 was within the interquartile range of 2002–2010, with the exception of the middle section of the Salmon River, which was within the interdecile range. Since the removal of Marmot Dam in 2007, the mean percentage of wild spawners in the primary spawning area of the upper Salmon River was 56% (SE ± 9.0%) in 2008–2011 and 58% in 2012. In the Zigzag River basin, the mean percentage of wild spawners in Still Creek was 63% (SE ± 7.3%) in 2008–2011 and 74% in 2012.

The ratio of redd density in the lower areas of the Salmon and Zigzag rivers to that in the upper Salmon River and Still Creek, respectively, was less variable in 2002–2010 than the ratio in the lower areas to the middle Salmon River or the upper Zigzag River, including Camp Creek

(Figure 11). Redd densities in the upper Salmon River and Still Creek were generally higher than those in the lower Salmon and Zigzag rivers, as indicated by ratios that were mostly < 1.0. In the Salmon River, the ratio of redd density in the lower area to the upper area in 2012 was similar to the 2002–2010 median whereas the ratio of the lower area to the middle area in 2012 was higher than the 2002–2010 interquartile range. In the Zigzag River, the ratios of redd density in the lower area to other areas in 2012 was within the interquartile range (Figure 11).

Within Salmon River, the mean percentage of wild spring Chinook salmon that spawned in the Wildwood–mouth section was 20% in 2002–2007 (excluding 2004 and 2006 because the section break was not recorded) compared to 19% in 2012. In the Zigzag River Basin, the mean percentage of wild fish that spawned downstream of Still Creek was 24% in 2002–2007 compared to 14% in 2012.

At the specific scale of the weir locations, the distribution of spawning by hatchery and wild spring Chinook salmon in the area downstream of the weir location in the lower Salmon River was higher in 2012 than in 1998 (Table 6). The distribution of wild spawners downstream of the weir in 2012 was similar to the distribution of all spawners in 1998. In contrast, the distribution of spawning in the Zigzag River downstream of the weir location was lower in 2012 than in 1997 (Table 6). However, inferences from these data are limited because annual variability in spawning distribution is high and numerous changes in the basin between the late 1990s and 2012 may have affected distribution, including changes in release number and location of hatchery fish and the removal of Marmot Dam.

Effect on Passage and Timing of Spawning

Although counts of live adult salmon downstream of the weirs provided only approximate estimates of fish abundance in the lower Zigzag and Salmon rivers, the counts indicated adult spring Chinook salmon were holding in pools downstream of the weirs. Larger numbers of adult salmon appeared to hold in the Salmon River downstream of the weir than in the Zigzag River (Tables 7–8, Figure 12). The count of adult fish in the immediate vicinity downstream of the weirs tended to follow the catch of adult fish in the traps (Figure 12). The count of adult spring Chinook in the lower Salmon River remained high after the trap catch peaked suggesting that fish continued to move out of the Sandy River and into the lower Salmon through early October. Timing of adult spring Chinook salmon trapped at Marmot Dam in 2002–2007 indicated a second migration peak in September, which was higher for fin-clipped fish than for unclipped fish (Figure 13).

Our weekly count of live spring Chinook salmon upstream of the weirs tracked well with the number of unclipped fish passed upstream (Figure 14). In the Zigzag River Basin, the number of live fish peaked during the same week as the trap catch (Figure 14a), whereas in the Salmon River Basin, the peak count of live fish occurred in the two weeks following the peak catch at the trap (Figure 14b). The catch of spring Chinook salmon in the Zigzag River trap increased earlier than the catch in the Salmon River trap (Figure 6). In addition, limited visibility of the Zigzag River because of glacial melt can affect the count of live fish.

The mean date of first spawning in the Salmon River Basin in 2002–2009 was similar to that in the Zigzag River Basin, but the variability was larger in the Zigzag River Basin (Figure 15).

The date of first spawning in 2012 was the same as the 2002–2009 mean in the lower Salmon River, and was earlier than the mean in the rest of the Salmon River and in the upper Zigzag River Basin, but within the range of previous years (Figure 15).

Peak spawning date was generally more variable in the Zigzag River Basin than in the Salmon River Basin (Figure 16). In the Salmon River upstream of Arrah Wanna, peak spawning in 2012 was later than the 2002–2010 mean date (but within the range), and peak spawning was about the same as the mean date downstream of Arrah Wanna. The date of peak spawning in 2012 was similar to the mean in Still Creek but was earlier than the 2002–2010 mean dates in the upper and lower Zigzag River (Figure 16).

Effect on Pre-spawning Mortality

Pre-spawning mortality of wild adult spring Chinook salmon in the Salmon and Zigzag rivers was slightly lower in 2012 than in 2003–2009, when weirs were not operated in the basin (Figure 17). The overall pre-spawning mortality of wild fish in the upper Sandy River Basin was also lower in 2012 than in previous years.

We found that pre-spawning mortality of unclipped spring Chinook salmon was variable in the upper Sandy River Basin (range = 0–17%), slightly lower than the variability observed in the upper McKenzie (range = 0–20%) or upper Clackamas (range = 0–29%) basins (Figure 18). However, the trend in pre-spawning mortality in the upper Sandy River Basin appears to generally track with the upper McKenzie and upper Clackamas river basins (Figures 18 and 19), suggesting regional factors common to several populations of spring Chinook salmon may be a primary influence on mortality.

Pre-spawning mortality was higher in hatchery fish than in wild fish (Table 9). We observed little or no difference in pre-spawning mortality in wild fish upstream and downstream of the weirs, although sample sizes of wild fish downstream of the weirs were much lower than upstream. In contrast, the pre-spawning mortality of hatchery fish was higher by 17–28% downstream of the weirs compared to upstream. Most of the hatchery fish recovered upstream of the weirs were fin-clipped and would not have been handled at the weir. In the Salmon River, the pre-spawning mortality of hatchery fish was about two times higher than that of wild fish upstream of the weir, and was almost five times higher than wild fish downstream of the weir (Table 9). Pre-spawning data in the Zigzag River were equivocal partly because the sample size for wild fish was small downstream of the weir. Pre-spawning mortality of hatchery fish downstream of the weir in the Zigzag River was about the same as that in the Salmon River, but no pre-spawning mortality of hatchery fish was documented upstream of the weir.

Abundance

Redd number and redd density of spring Chinook salmon were highest in the upper Salmon River section and in Still Creek (Table 10). These areas have generally supported the greatest concentration of spawning since we began surveying the upper Sandy River Basin in 1996. Biologists from City of Portland Water Bureau reported three redds in the Little Sandy River in 2012, but thought that at least two were from coho salmon *O. kisutch* (B. Strobel, City of Portland Water Bureau, personal communication). We counted 34 redds in the Little Sandy River in 2011, and U. S. Forest Service biologists counted 10 redds in 2010. CoPWB biologists also counted 28 redds in the Bull Run River in 2012, compared to a mean of 45 redds (range = 22–69) in 2002–2007 and 51 redds (range = 34–67) in 2008–2011 after the removal of Marmot Dam.

Our estimate of spring Chinook salmon in the upper Sandy River Basin using the relationship of Marmot Dam counts to redds in 2002–2007 indicated the number of wild fish in 2012 was over twice that of the 2002–2007 when fin-clipped fish were removed at Marmot Dam (Table 11, Figure 20). The number of hatchery fish in 2012 was 62% less than in 2008–2011. Compared to 2011, the number of wild fish increased 2.7 times and the number of hatchery fish decreased 42%. By comparison, the number of wild spring Chinook salmon increased just 8% from 2011 to 2012 in the Clackamas River Basin upstream of North Fork Dam (Figure 20), and the number of hatchery fish counted at the dam decreased about 30%. However, the count of hatchery fish at North Fork Dam does not include those that entered Clackamas Hatchery downstream of the dam.

Our estimate of spring Chinook salmon in the upper Sandy River Basin derived from redd counts indicated that the wild fish component was 2.4 times higher in 2012 than in 2011 (Table 11), which is similar to that estimated from the Marmot Dam-to-redd relationship. We estimated the number of wild spring Chinook salmon in 2012 was the highest since 2002 when hatchery and wild fish could be identified by origin (Table 11). The number of hatchery spring Chinook salmon in the upper Sandy River Basin decreased 57% from 2011 to 2012 (Table 11), which is greater than that estimated from the dam count-to-redd relationship. However, when the hatchery fish trapped and removed from the Salmon and Zigzag rivers were added, we estimated a 44% decrease in hatchery fish from 2011 to 2012, which is similar to the decrease derived from the dam count-to-redd relationship.

The estimated number of wild spawners in the Salmon River Basin in 2012 was about twice as high as the mean number in 2002–2007 and 2008–2011 (Table 12). In the Zigzag River Basin, the number of wild spawners in 2012 was twice that of the 2002–2007 mean and over three times the mean number in 2008–2011. The estimated number of wild spawners in Lost, Clear Fork, and Clear creeks was relatively small in 2012, but was the second highest since 2002. The estimated number of hatchery spawners in the Salmon and Zigzag River basins was about 70% lower in 2012 than in 2008–2011 following the removal of Marmot Dam (Table 12). The decrease is attributable to a lower return of hatchery spring Chinook to the upper Sandy River Basin and to the removal of fin-clipped fish at weirs. However, the number of hatchery spawners was much higher in 2012 than in 2002–2007 when fin-clipped fish were removed at Marmot Dam. In contrast, the number of hatchery spawners in the tributaries was higher in 2012 than in previous years.

DISCUSSION AND SUMMARY

Removal of fin-clipped spring Chinook salmon at weirs in the lower Salmon and Zigzag rivers resulted in a reduction of hatchery origin spawners of 41% in the Sandy River Basin. We estimated that the percentage of hatchery spawners in the upper Sandy River Basin was reduced from 44% to 24%. In addition, the percentage of hatchery spawners upstream of the weirs was reduced by 70% and 65% in the Salmon and Zigzag River basins, respectively. Areas upstream of the weirs represented 78% of all spawning by spring Chinook salmon in the upper Sandy River Basin in 2012 and 76% when the Bull Run River is included. Although additional actions to reduce pHOS in the upper Sandy River Basin can target specific areas based on the distribution of fin-clipped fish, some actions may have a greater functional benefit in reducing the effect of hatchery spawners depending on the distribution and number of unclipped spawners within the basin. For example, we have found relatively high numbers of hatchery spawners in Lost and Clear Fork creeks in the past few years and weirs could be installed in these streams to remove hatchery fish. However, because few wild fish use these streams, a greater benefit to the population of spring Chinook salmon in the upper Sandy River Basin could be achieved by further reducing hatchery fish in primary spawning areas of the Salmon and Zigzag River basins.

We observed adult spring Chinook salmon in the Salmon and Zigzag rivers downstream of the weirs, with especially large numbers in the lower Salmon River. Because of our observations, district staff increased attraction flow and monitoring at the weirs as a precaution. Potential effects of operating the weirs would be delayed migration, prevention of migration into primary spawning areas upstream of the weirs, distribution of spawners into the lower river, and increased mortality. Although observations of live fish are a potential indicator of weir effects, the primary indicator is the distribution of spawning and pre-spawning mortality. Our assessment of the potential effect of weirs on spawning distribution at the scale of specific weir location was limited because we lacked data prior to 2012 on redd locations relative to weir locations. Within the relatively short sections in the immediate vicinity of the weirs, we noted an increase in distribution of spawners downstream of the weir location in 2012 compared to the late 1990s in the lower Salmon River, but the distribution of spawners in the lower Zigzag River was smaller in 2012 than in the late 1990s. However, these data are of limited use in evaluating changes in distribution as a result of the weirs, because distribution within sections of rivers varies and because changes in hatchery fish management and the removal of Marmot Dam may also have affected distribution between the late 1990s and 2012. In addition, the metric of assessing the effect of weirs is at the larger geographic scale of watersheds rather than at the smaller scale of areas immediately upstream and downstream of weirs.

Although the effect of weirs might alter spawning distribution in areas immediately upstream and downstream of weirs, effects of weirs on the distribution of wild fish into the primary spawning areas of the upper basins is probably more important. The percentage of spring Chinook salmon spawning in the upper Salmon and Zigzag River basins has represented over 75% of all documented spawning in the Sandy River Basin. We found a slightly higher distribution of wild spawners in the upper Salmon River in 2012 than in 2008–2011, following the removal of Marmot Dam, and an increase in spawning distribution in Still Creek of about 10% in 2012 compared to 2008–2011.

Attributing changes in spawning distribution to an effect of weirs is difficult without an adequate monitoring design (e.g., impact study design, Green 1979) to assess factors such as the variability in spawning distribution among survey sections and changes in channel configuration and gravel distribution from natural events and restoration projects. For example, the removal of Marmot Dam in 2007 may have affected the migration timing of spring Chinook salmon because of increased flows and unobstructed passage, and because fish would no longer be falsely attracted to the Bull Run River by the diversion of Sandy River water. A change in migration timing could subsequently affect spawning distribution in the upper Sandy River Basin.

Spawning distribution as measured by the percentage of spawners among sections of a basin varies annually in the Sandy River Basin. Consequently, the metric for measuring change in distribution should be at an absolute percentage change rather than in a relative change in percentage. For example, if the metric for measuring effect was a 20% change in distribution and the baseline percentage of spawning in a section was 15%, an absolute percentage change would be 35% whereas a relative change would be 18%.

Many factors can affect spawning distribution including environmental factors (e.g., flow and water temperature), distribution of spawning gravel, and run timing of adults to spawning areas. Spawning distribution can also change over longer periods because of watershed changes caused by events such as floods and landslides. The upper Sandy River Basin has experienced two major flood events in recent years. Flows in January 2009 and January 2011 exceeded 25,000 cfs and resulted in channel changes in the Sandy and Zigzag rivers (English 2013). As a result of these and smaller flood events the channel location, gravel location, and gravel quantity have changed several times in the lower Zigzag River over the last 10 years. Although operating a weir in the lower Zigzag River may have had an effect on distribution of spawning by spring Chinook salmon, the specific effect of the weir would be difficult to separate from the overall effect on spawning distribution of fluvial changes in the lower river.

In the lower Salmon River, BLM has implemented restoration projects, most of which are downstream of the present weir location. One of the objectives of the restoration is to “provide high quality spawning and rearing habitat in main channel and side-channel habitats for anadromous fish”, and restoration actions are intended to “increase pool habitat and spawning areas at pool tail-outs by restoring three additional main channel riffle-pool-riffle habitat sequences” (BLM 2010). Therefore, although operating a weir in the lower Salmon River may affect spawning distribution, restoration actions could also affect the amount of spawning gravel and holding pools in the lower river.

The biological and population-level effects of a change in spawning distribution would depend on several factors including quality and quantity of spawning gravel, timing of spawning, and water quality (e.g., flow and water temperature). Availability and quality of spawning gravel are two factors that influence the use of specific stream sections for spawning and can affect the subsequent biological implications of spawning in certain locations. In addition, location of spawning within a basin may affect egg incubation and emergence success of salmon depending on factors such as water temperature.

Spring Chinook salmon spawning in the lower reaches of the Salmon and Zigzag rivers would likely have high spawning success because they are within the preferred and historic spawning areas. In contrast, spring Chinook salmon spawning in the lower Bull Run River are confined to the very lower reach of that watershed, which is not where they historically spawned. The overall spawning success is likely to be lower in the Bull Run River than in the lower Salmon or Zigzag river because of limited spawning gravel and an altered hydrologic regime downstream of the dams.

The use of the lowermost sections of the Salmon and Zigzag rivers for spawning by spring Chinook salmon has been observed since ODFW began large-scale surveys of the upper Sandy River Basin in 1996. In 2002–2007 when fin-clipped fish were removed at Marmot Dam, the mean percentage of wild spring Chinook salmon that spawned in the lower section (Wildwood Park to the mouth) was 20%, compared to 19% in 2012. The mean percentage of spawning by wild fish in the lowermost section of the Zigzag River (Still Creek to the mouth) was 24% in 2002–2007, compared to 14% in 2012.

Timing of spawning can depend on environmental factors and their effects on migration and maturation timing. Estimating the timing of spawning with stream surveys can depend on factors such as frequency of surveys and changes in water conditions (e.g., water clarity and flow) during the survey season. Survey factors likely affect estimates of peak spawning more than estimates of first spawning because the latter requires the observation of a single redd anywhere in a survey section whereas peak spawning requires a complete count of redds. We found little evidence that operation of the weirs delayed the timing of spawning in the Salmon or Zigzag River basins. The date of first spawning in 2012 was similar to the mean date in previous years in the lower Salmon River, and was earlier in the upper Salmon and upper Zigzag River basins than the mean date (but within the range). Peak spawning in 2012 was similar to the mean date in previous years for the lower and middle Salmon and for Still Creek, and was within the range of peak spawning dates in other areas of the Salmon and Zigzag River basins.

Several factors can contribute to pre-spawning mortality. Because the physiological condition of salmon deteriorates as they migrate upstream, hold, and approach their spawning season, their immune system deteriorates. As a result, stress factors such as high water temperature, injuries sustained during upstream migration, disease, and handling can accelerate the process of deterioration to the point that the fish dies before spawning. A possible effect of trapping adult salmon is increased pre-spawning mortality caused by factors such as injury in the trap and netting and handling.

We found no evidence that trapping adult spring Chinook salmon in the lower Salmon and Zigzag rivers increased pre-spawning mortality in wild fish. Pre-spawning mortality of wild fish in the upper Sandy River Basin was lower in 2012 than in previous years. Annual variability in pre-spawning mortality and correlation among basins make it difficult to attribute an observed change in mortality to a single factor such as operation of weirs. Nonetheless, handling of adult salmon at the traps appeared to have no effect on the subsequent pre-spawning mortality of wild fish upstream of the weirs.

Overall, pre-spawning mortality was lower in wild spring Chinook salmon than in hatchery fish. Pre-spawning mortality relative to the weir locations in the Salmon River suggested little or no effect for wild fish (although sample sizes of wild fish downstream of the weirs was small), and a potential effect on hatchery fish holding downstream. Data for the Salmon River suggested hatchery fish were more vulnerable to mortality factors than wild fish upstream or downstream of the weir. Pre-spawning mortality data in the Zigzag River were equivocal partly because wild fish recoveries were very low downstream of the weir, and no pre-spawning mortality of hatchery fish was documented upstream of the weir.

Our results indicate that trapping in the primary spawning tributaries reduced the number and percentage of hatchery spawners with little or no effect on timing and pre-spawning mortality, and no clear effect on spawning distribution. Although operation of weirs may have affected distribution of spawning in limited areas immediately upstream and downstream of the weirs pHOS was reduced upstream of the weirs, and these sections represented almost 80% of all spawning in the upper Sandy River Basin. In addition, although the density of spawners downstream of the weirs appeared to be greater in 2012 than in previous years, these spawners were composed of 53% and 55% hatchery fish in the lower Salmon and Zigzag rivers, respectively. The area downstream of the weirs contained just 15% of all redds observed in 2012.

In summary, we found that trapping and removing fin-clipped spring Chinook salmon reduced the number and percentage of hatchery spawners in the primary spawning areas of the upper Sandy River Basin. Estimated pHOS for the upper Sandy River Basin remained higher than the 10% performance standard, and was 12% and 14% in areas upstream of the weirs where most of the spawning occurs. Refinement of trapping such as relocating weirs farther downstream or operating traps earlier in the year may succeed in reducing pHOS to less than 10%. In addition, the first returns of hatchery Chinook salmon that were released into the Bull Run River will return in 2013, and the installation of a trap to remove returning hatchery fish may further reduce the number of hatchery fish migrating into the upper Sandy River Basin. The strategy of decreasing the number of juvenile hatchery fish released and releasing all of them in the Bull Run River was implemented in 2013 and should further reduce the number and proportion of hatchery spawners.

ACKNOWLEDGMENTS

We thank the many seasonal biologists who collected much of the field data for this study. Our primary Sandy Basin surveyors were Adam Wicks-Arshack, Chris Harman, Janus Kober, and Chris Lessick, with assistance from Sara Akins, Allen Gillette, David Hewlett, and Anthony Newbold. Thanks to David Hewlett for preparing maps of redd locations. ODFW district biologists Todd Alsbury and Justin Zweifel provided logistical support at their Clackamas office, and provided trap operations data. Kathryn Arendt (U. S. Forest Service) and Bruce Zoellick (Bureau of Land Management) provided information and input on spawning surveys.

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TABLES

Table 1. Percentage of spring Chinook salmon carcasses with fin clips that were recovered in the Sandy River Basin, 2012.

River/stream	Section	Percent clipped	Sample size
Salmon River	Final Falls–Forest Rd 2618	8	271
	Forest Rd 2618–Arrah Wanna	4	138
	Arrah Wanna–weir	8	107
	Weir–mouth	46	77
Salmon Basin Total		**12**	**593**
Zigzag River	Above Camp Creek	0	0
	Camp Creek–Still Creek	47	15
	Still Creek–weir	9	45
	Weir–mouth	53	99
Zigzag River Total		40	159
Still Creek	Above Rd 20 Bridge	7	116
	Below Rd 20 Bridge	9	156
Still Total		8	272
Camp Creek	Campground–mouth	16	44
Zigzag Basin Total		**19**	**475**
Lost Creek	Riley Campground–mouth	81	57
Clear Fork	Mouth area	67	48
Bull Run River	Dam–mouth	40	5
GRAND TOTAL		**21**	**1,178**

Table 2. Percentage of spring Chinook salmon carcasses that were hatchery origin in six areas of the Sandy River Basin, 2012.

Basin	Area	Percent hatchery	Sample size
Salmon	Upstream of weir	12.1	516
	Downstream of weir	53.4	77
	Total	**19.7**	**593**
Zigzag	Upstream of weir	14.4	376
	Downstream of weir	56.1	99
	Total	**20.3**	**475**
Lost & Clear Fork creeks	All surveyed areas	78.8	105
Bull Run River	Dam–mouth	40.0	5

Table 3. Number of spring Chinook salmon at traps in the Salmon and Zigzag rivers, 2011 and 2012. Fin-clipped fish were removed and unclipped fish were passed upstream. Traps were installed by ODFW District biologists to capture and remove fin-clipped salmon.

	Zigzag		Salmon	
	2011	2012	2011	2012
Dates	Aug 19–Sep 27	Jul 4–Oct 14	Sep 14–Oct 4	Jun 18–Oct 14
Fin-clipped	183	188	229[a]	247
Not clipped	91	432	94	1,108

[a] *An additional 44 clipped Chinook were netted and removed prior to the trap installation*.

Table 4. Effect of trapping and removing fin-clipped spring Chinook salmon at weirs in the lower Zigzag and Salmon rivers on the proportion of hatchery spawners in the Salmon and Zigzag River basins and in the upper Sandy River Basin, 2012.

		Hatchery spawners (%)	
Basin	Number removed	With trapping	Without trapping
Salmon	247	19.7	42.4
Zigzag	188	20.3	43.1
Upper Sandy River	435	23.7	44.3

Table 5. Estimated number of adult spring Chinook salmon in the Salmon and Zigzag River Basins upstream of weirs, count of fish at the weirs, and the estimated percentage of uncounted fish at the weirs (migrated prior to weir installation or escaped uncounted at the weirs). The percentage of uncounted fish that were unclipped was from the difference between the estimated number upstream of the weir and the number passed at the weir. The percentage of unaccounted fin-clipped fish was based on the total of fin-clipped fish removed at the weir and the estimated number of fin-clipped fish upstream.

		Estimated number[a]			Weir count		Not counted (%)	
Basin	Redds	Total	Unclipped	Fin-clipped	Unclipped	Fin-clipped	Unclipped	Fin-clipped
Salmon	465	1,395	1,295	97[b]	1,108	247	14.4	28.2
Zigzag	366	1,098	981	117	432	188	56.0	38.3

[a] *Redds x 3.0 fish/redd and percentage of unclipped and fin-clipped carcasses recovered upstream of weirs.*
[b] *Accounts for 3% of fin-clipped fish in the Salmon River that were estimated to have passed upstream after the weir was removed.*

Table 6. Distribution of hatchery and wild spring Chinook salmon spawning (redds) in the late 1990s and 2012 in the areas of the Salmon and Zigzag River basins downstream of the 2012 weir locations as a percentage of all redds in the basins. Distribution of wild spawners in 2012 was based on recovery of wild-origin carcasses.

		2012	
Area	Late 1990s	All fish	Wild spawners
Salmon River below weir	9	18	11
Zigzag River below weir	17	14	6

Table 7. Spring Chinook salmon in the Salmon River Basin counted at the weir and live fish counts upstream and downstream of the weir, and in the immediate (~ 100 ft) vicinity downstream of the weir, 2012.

	Weir count		Live fish		
Week	Unclipped	Fin-clipped	Above weir	Below weir	Weir vicinity
Jun 17	13	0	--	--	0
Jun 24	6	6	--	--	2
Jul 1	12	0	--	--	0
Jul 8	45	1	--	--	2
Jul 15	27	0	--	--	9
Jul 22	37	0	--	--	15
Jul 29	9	1	--	--	0
Aug 5	112	5	--	--	55
Aug 12	26	2	--	--	13
Aug 19	2	0	1	500	0
Aug 26	3	0	34	--	0
Sep 2	10	1	61	500	12
Sep 9	179	39	67	450	110
Sep 16	488	111	283	600	232
Sep 23	112	63	397	623	157
Sep 30	19	17	388	400	123
Oct 7	8	7	72	200	124
Oct 14	--	--	10	--	--
Oct 21	--	--	16	3	--

Table 8. Spring Chinook salmon in the Zigzag River Basin counted at the weir and live fish counts upstream and downstream of the weir, and in the immediate (~ 100 ft) vicinity downstream of the weir, 2012.

	Weir count		Live fish		
Week	Unclipped	Fin-clipped	Above weir	Below weir	Weir vicinity
Jul 1	4	1	--	--	0
Jul 8	19	2	--	--	0
Jul 15	4	4	--	--	0
Jul 22	5	0	--	--	1
Jul 29	4	1	--	--	0
Aug 5	17	4	--	--	0
Aug 12	20	6	--	--	1
Aug 19	1	2	3	50	0
Aug 26	6	0	2	--	0
Sep 2	78	19	0	40	77
Sep 9	91	48	8	17	70
Sep 16	141	60	66	112	109
Sep 23	29	27	23	62	16
Sep 30	8	13	16	25	19
Oct 7	5	1	1	25	3

Table 9. Percentage of wild and hatchery spring Chinook salmon females that died prior to spawning as determined by presence of eggs (sample size in parentheses) for the Salmon and Zigzag river basins, 2012.

	Wild			Hatchery		
Basin	Above weir	Below weir	Total	Above weir	Below weir	Total
Salmon	5.5 (164)	5.9 (17)	5.5	10.0 (30)	26.9 (26)	17.9
Zigzag	2.1 (96)	0.0 (8)	1.9	0.0 (27)	27.6 (29)	14.3

Table 10. Redd counts and red density (redds/mi) of spring Chinook salmon in the upper Sandy River Basin, 2002-2012.

Basin, section	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
						Redds					
Salmon River:											
Final Falls–Forest Rd 2618	53	60	233	84	139	79	395	139	387	173	314
Forest Rd 2618–ArrahWanna	68	29	188	62	45	54	181	61	299	151	89
ArrahWanna–mouth	69	38	179	146	67	58	121	39	168	161	167
Zigzag River:											
Still Creek	62	28	108	79	117	28	405	162	550	152	291
Above Still Creek & Camp Cr	11	5	25	21	12	13	75	52	135	108	55
Still Creek–mouth	5	19	48	31	36	27	109	36	59	122	80
Other streams:											
Lost Creek	6	7	20	11	9	9	27	9	5	32	45
Clear Fork Creek	0	--	0	--	--	--	1	1	2	10	24
Clear Creek	0	0	0	0	2	3	0	0	3	--	--
TOTAL	**274**	**186**	**801**	**434**	**427**	**271**	**1,314**	**499**	**1,608**	**909**	**1,065**
						Redds/mi					
Salmon River:											
Final Falls–Forest Rd 2618	16.6	17.8	69.1	26.3	43.4	24.7	117.2	43.4	114.8	54.1	93.2
Forest Rd 2618–ArrahWanna	12.6	3.9	25.4	11.5	8.3	10.0	33.5	8.2	40.4	20.4	12.0
ArrahWanna–mouth	13.8	7.6	35.8	29.2	13.4	11.6	24.2	7.8	33.6	32.2	33.4
Zigzag River:											
Still Creek	18.8	5.6	32.7	15.8	35.5	8.5	81.0	32.4	109.2	30.4	58.2
Above Still Creek & Camp Cr	2.8	1.3	6.3	5.3	3.0	3.3	41.7	8.8	22.9	18.3	9.3
Still Creek–mouth	2.3	8.6	21.8	14.1	16.4	12.3	49.5	16.4	26.8	55.5	36.4
Other streams:											
Lost Creek	3.0	3.5	10.0	5.5	4.5	4.5	13.5	4.5	2.5	16.0	22.5
Clear Fork Creek	0.0	--	0.0	--	--	--	1.7	1.7	3.3	16.7	40.0
Clear Creek	0.0	0.0	0.0	0.0	4.0	6.0	0.0	0.0	6.0	--	--

Table 11. Estimated number of wild and hatchery spring Chinook salmon in the upper Sandy River Basin (upstream of Marmot Dam site), 2002–2012. Origin of fish was based on recovery of carcasses and presence or absence of an adipose fin clip, and presence or absence of induced thermal marks in fish without a fin clip or with unknown fin clip status.

	Marmot Dam[a]		Redd Counts[b]	
Return year	Wild	Hatchery	Wild	Hatchery
2002	919	201	580	105
2003	871	125	400	65
2004	2,416	88	1,946	57
2005	1,335	250	905	180
2006	1,070	114	976	92
2007	1,302	108	601	77
2008	2,721	2,244	1,703	1,582
2009	856	965	672	576
2010	1,391	4,685	930	3,090
2011	1,150	2,284	836	1,436
2012	3,070	954	2,045	618

[a] *Dam counts through 2007. Estimated from relationship of redds to counts or fish/redd to counts* (see **Methods**).
[b] *Estimated redd counts and 2.5 fish per redd* (see **Methods**).

Table 12. Estimated number of spring Chinook salmon spawners of wild and hatchery origin in the upper Sandy River Basin, 2002–2012. Spawner number was estimated by assuming 2.5 spawners per redd. Origin was estimated from presence or absence of adipose fin clips in recovered carcasses and from presence or absence of induced thermal marks in otoliths of carcasses without an adipose fin clip. Totals may not match those in Table 11 because of rounding.

Basin	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
					Wild						
Salmon	409	268	1,482	626	586	416	988	415	541	453	1,171
Zigzag	164	115	414	260	369	170	688	242	390	382	840
Tributaries[a]	6	18	50	18	21	15	27	16	0	2	34
					Hatchery						
Salmon	66	50	18	104	41	62	754	183	1,594	760[b]	254[c]
Zigzag	31	15	39	67	44	0	784	383	1,470	573[b]	225[c]
Tributaries[a]	9	0	0	9	7	15	43	10	25	103	139

[a] *Lost, Clear Fork, and Clear creeks.*
[b] *Does not include trapped or netted fish removed in the Salmon (273) and Zigzag (183) rivers.*
[c] *Does not include trapped fish removed in the Salmon (247) and Zigzag (188) rivers.*

FIGURES

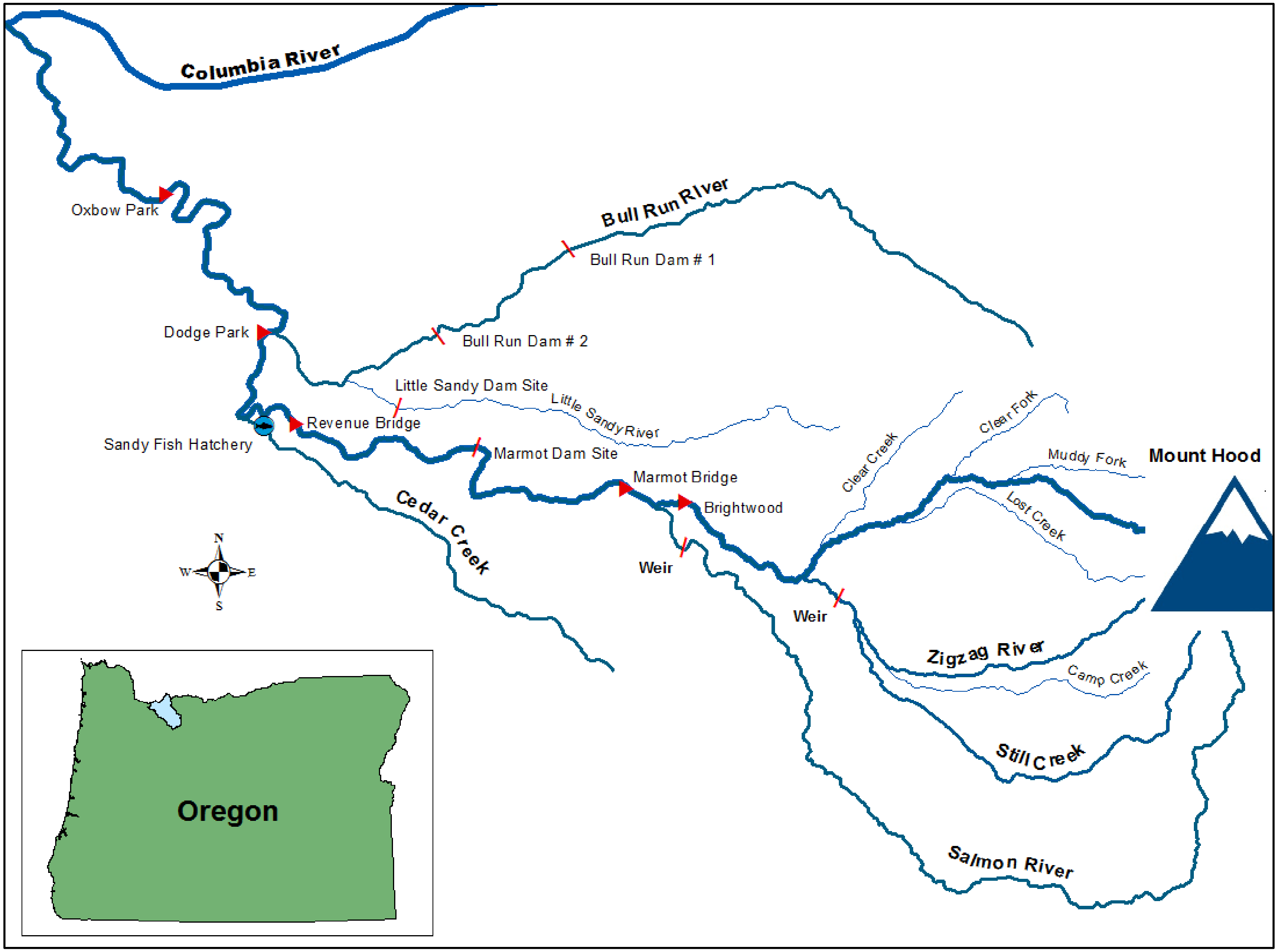

Figure 1. The Sandy River Basin, including tributaries with spawning populations of spring Chinook salmon.

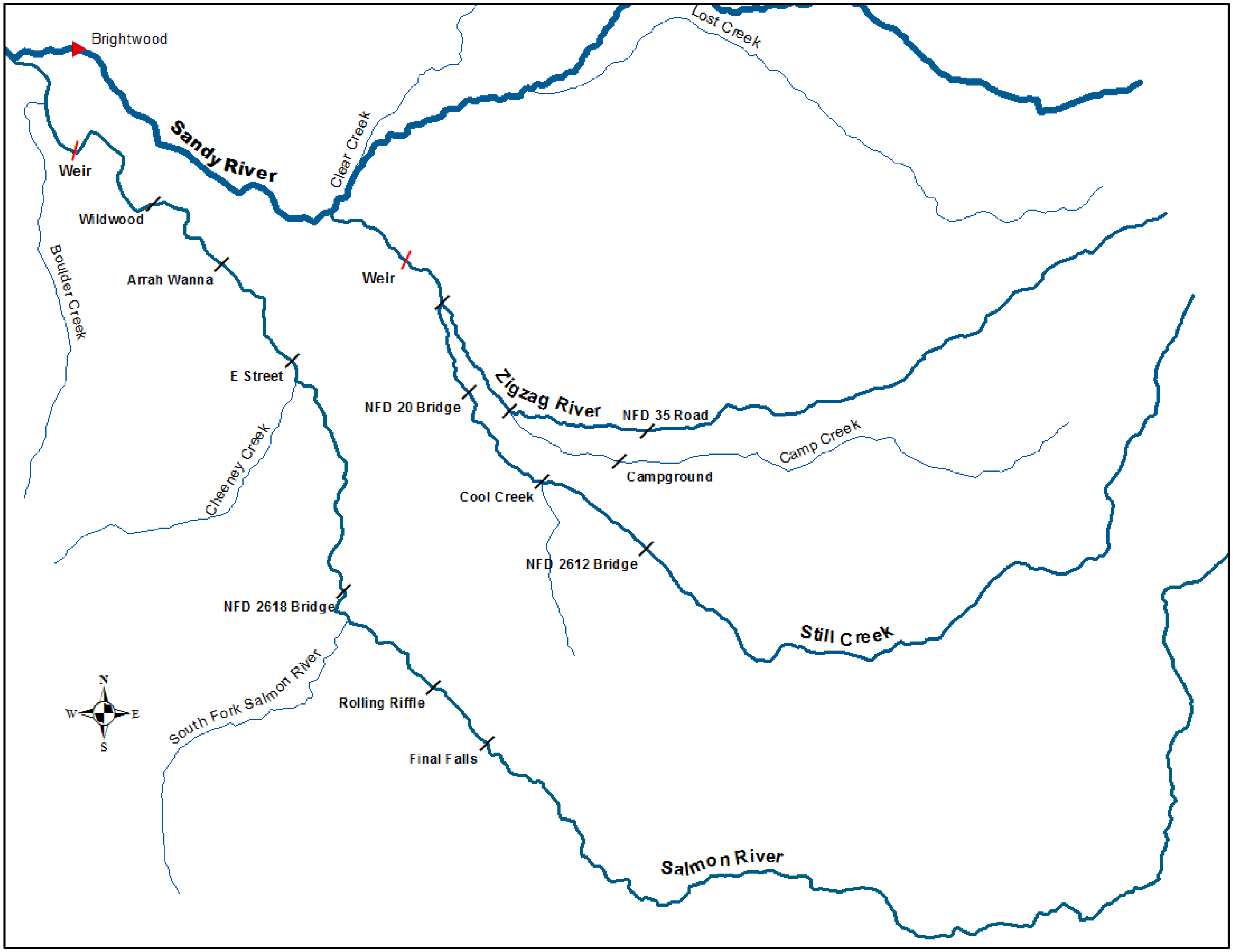

Figure 2. The upper Sandy River Basin with weirs locations and section breaks on major spawning tributaries.

Figure 3. Sandy River near the entrance to the Marmot Dam fishway, July 1939. Photo by Ed Brockman (http://oregondigital.org/u?/streamsurve,724).

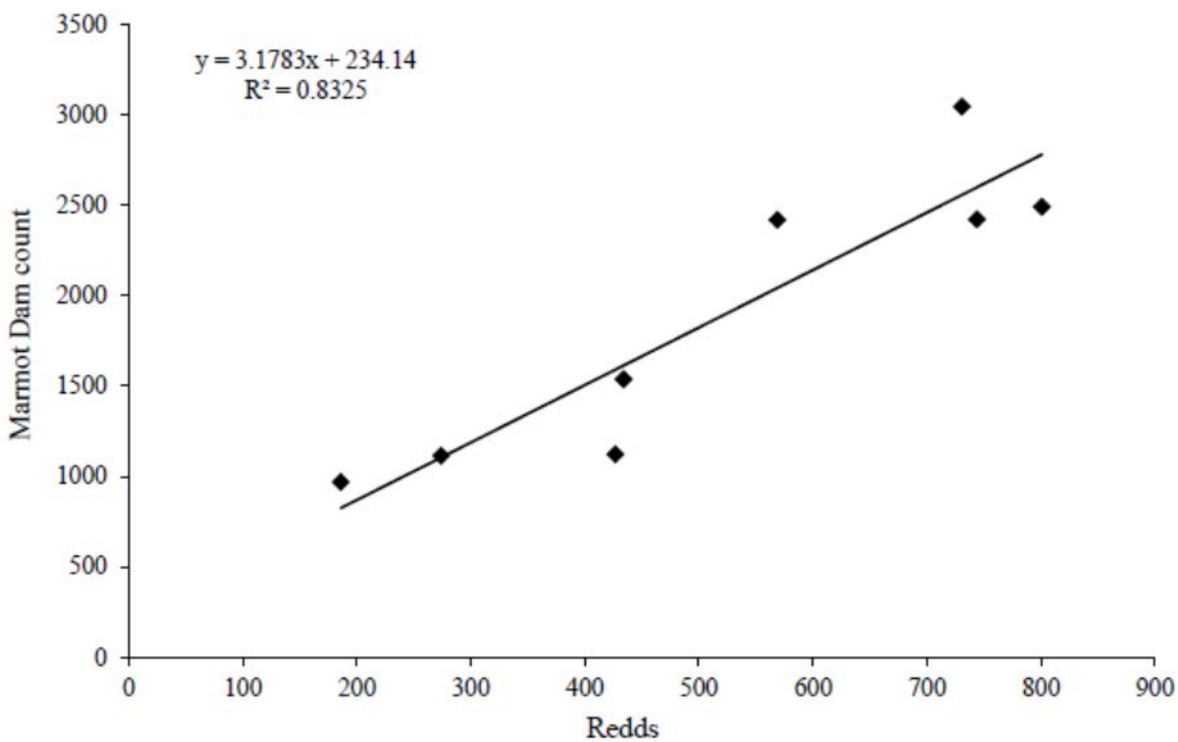

Figure 4. Relationship between counts of adult spring Chinook salmon at Marmot Dam and the number of redds counted upstream of the dam, 1996–1998 and 2002–2006.

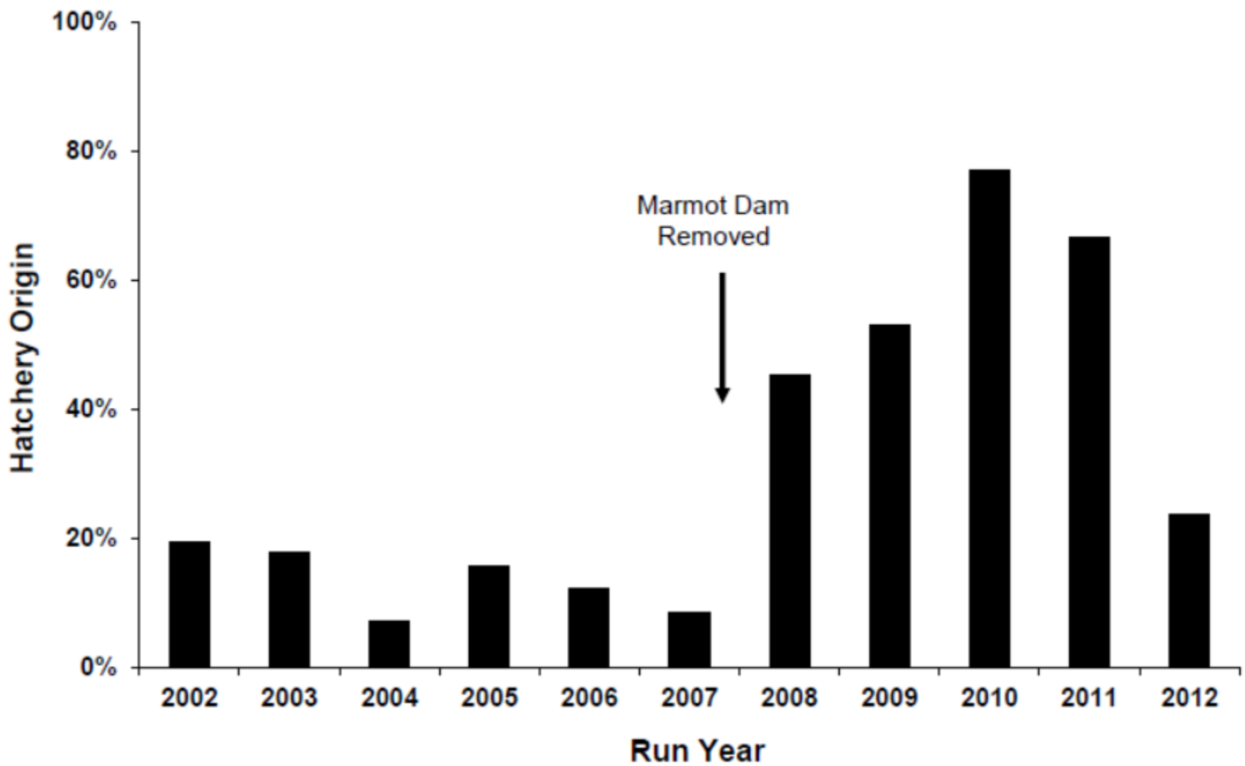

Figure 5. Percentage of hatchery-origin spring Chinook salmon in the spawning population of the Sandy River Basin upstream of the Marmot Dam site, 2002–2012.

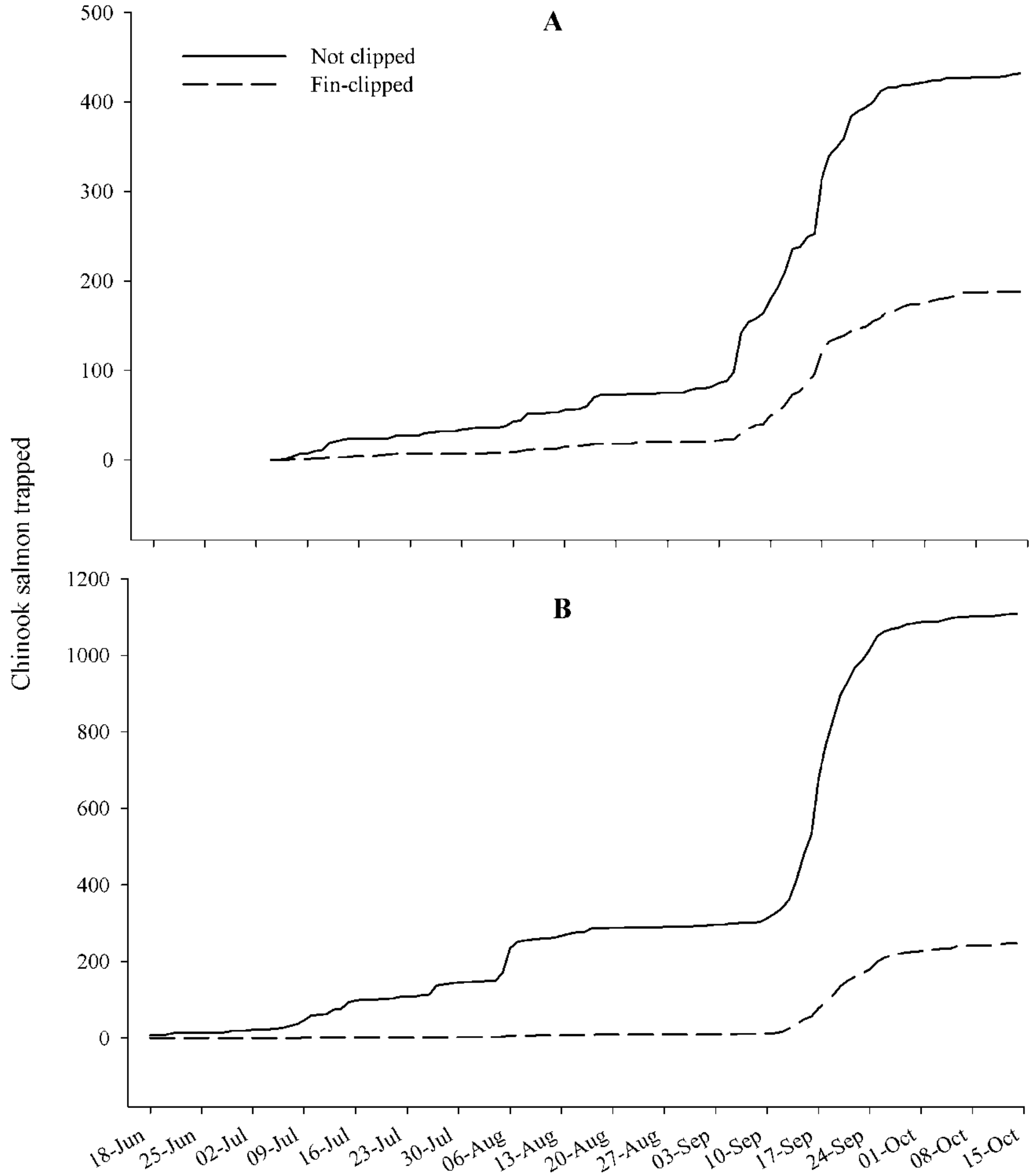

Figure 6. Cumulative number of spring Chinook salmon handled at weirs in the lower Zigzag (A) and Salmon (B) rivers, for fish with an adipose fin clip (dashed line) and without a fin clip (solid line), 2012. Note different Y-axis scale.

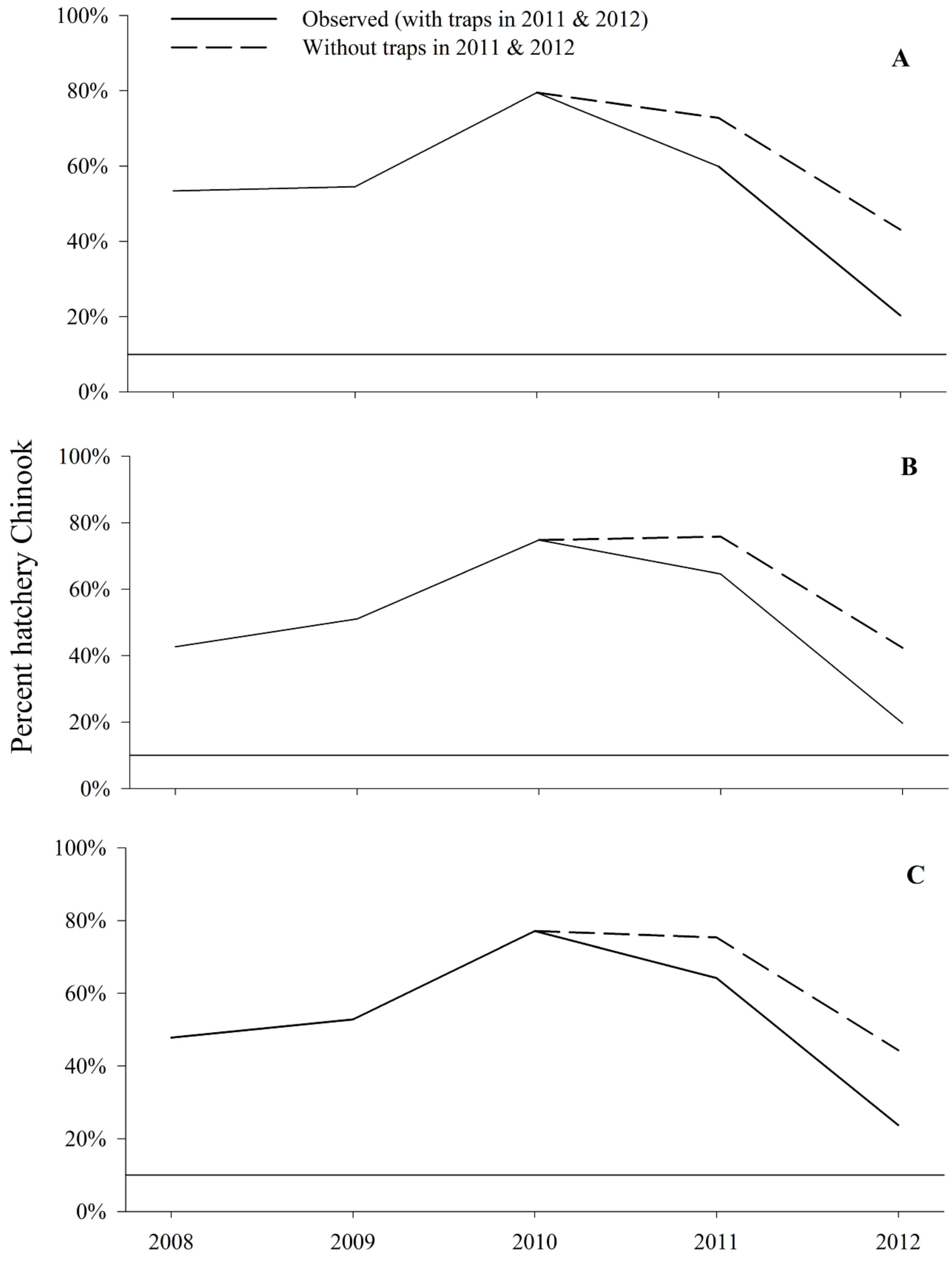

Figure 7. Percentage of hatchery spring Chinook salmon in the Zigzag (A) and Salmon (B) river basins, and in the upper Sandy River Basin (C), 2008–2012. Traps were operated in the lower Salmon and Zigzag rivers in 2011 and 2012 to remove fin-clipped fish. Estimated percentage of hatchery spawners without trapping is shown by dashed lines. The 10% line represents conservation and recovery objectives for the proportion of hatchery spawners.

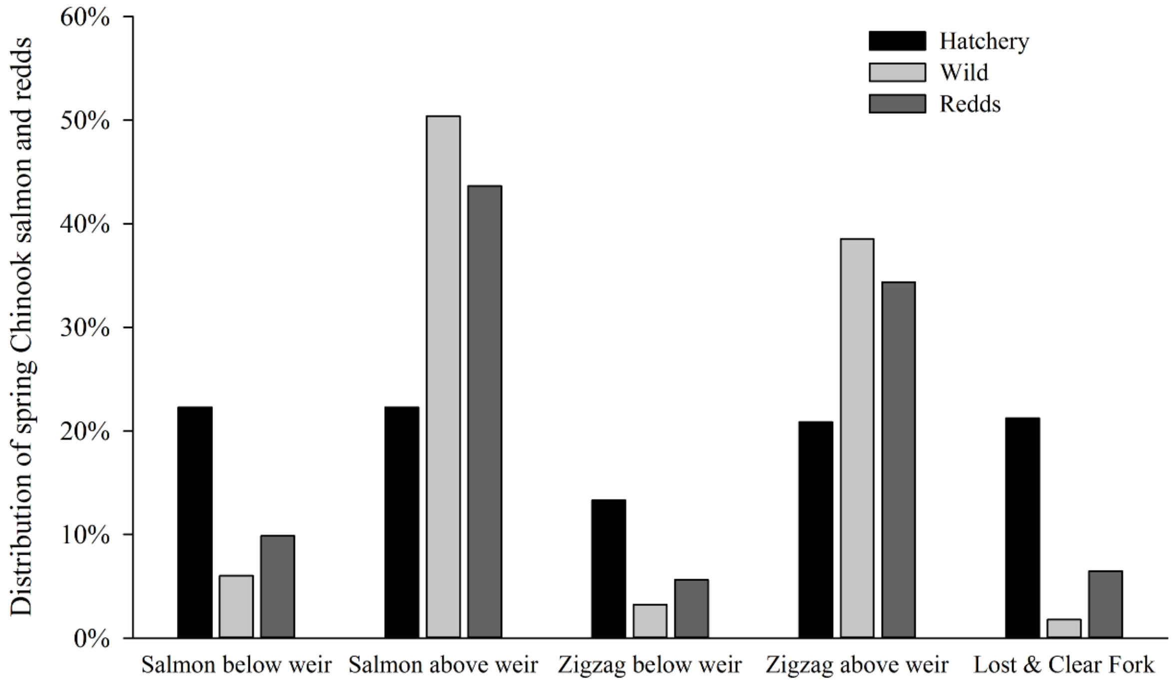

Figure 8. Distribution of spring Chinook salmon carcasses (hatchery and wild origin) and redds in five areas of the upper Sandy River Basin, 2012.

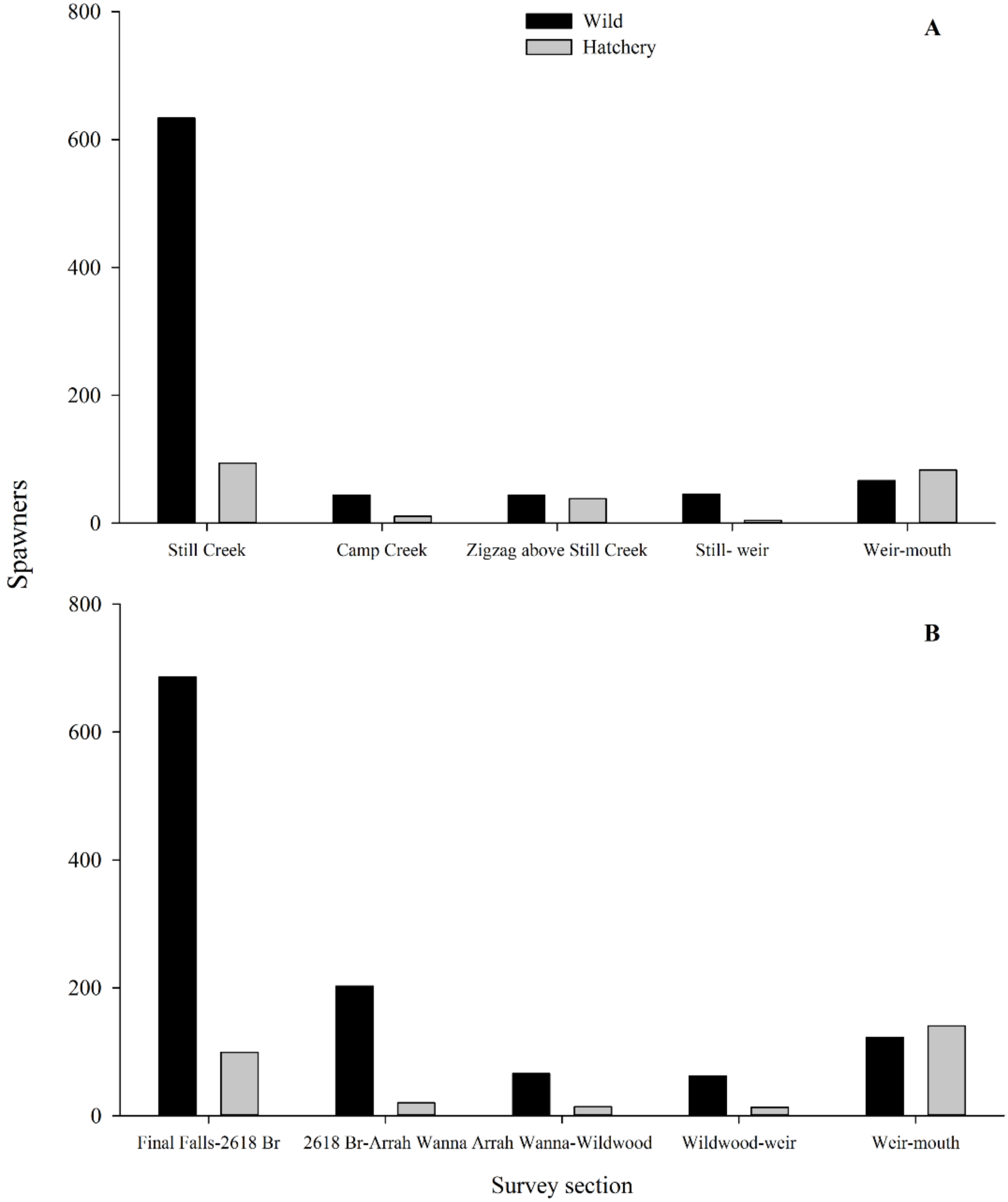

Figure 9. Distribution of wild and hatchery spring Chinook salmon spawners in the Zigzag (A) and Salmon (B) river basins, 2012.

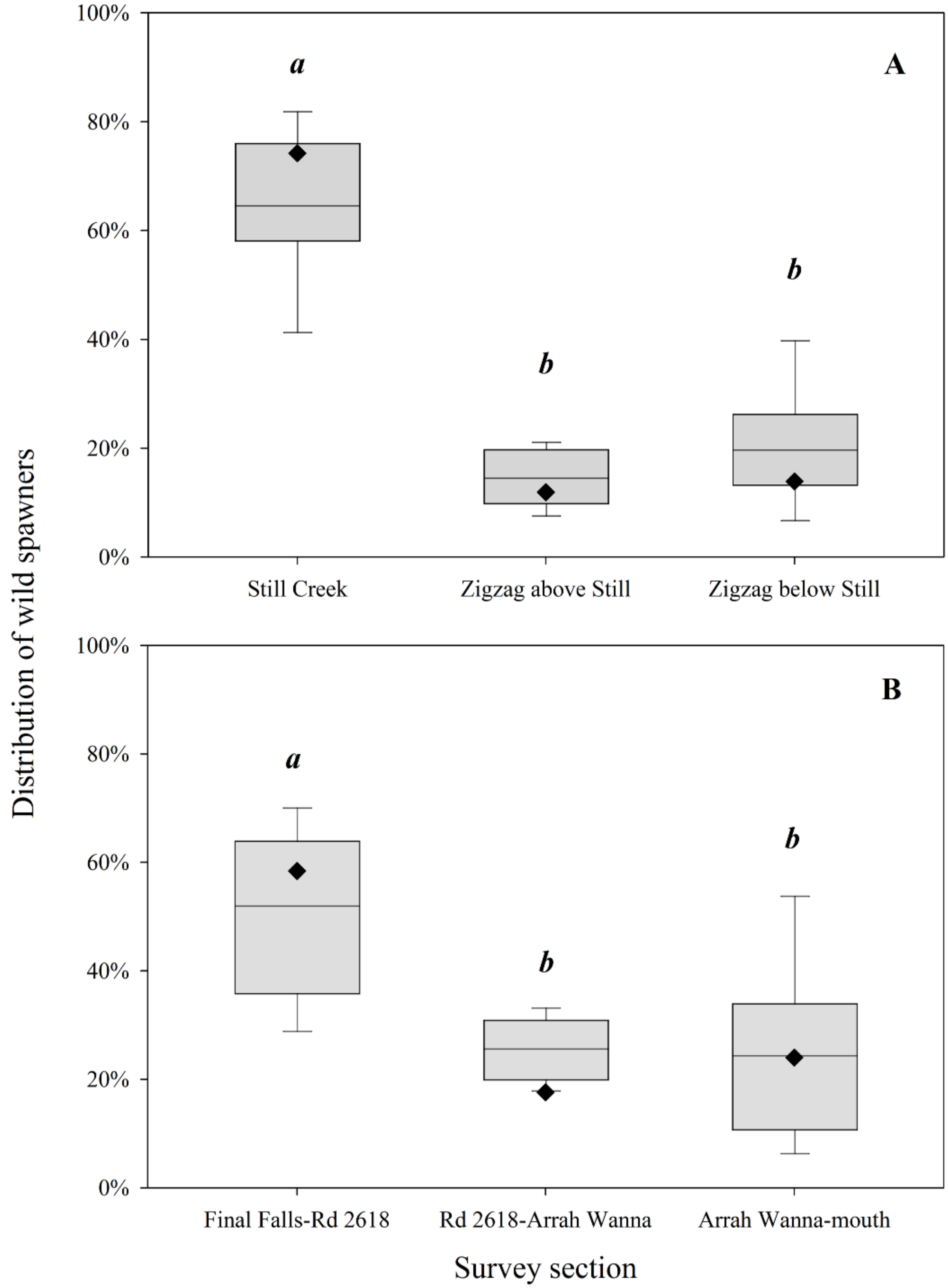

Figure 10. Distribution of spawning by wild spring Chinook salmon within Zigzag (A) and Salmon (B) river basins in 2002–2010 (box plots) and in 2012 (♦). Horizontal lines within boxes denote medians, boxes encompass the 25th and 75th percentiles, and whiskers denote the 10th and 90th percentiles. Boxes without a letter in common are significantly different (*P* < 0.01).

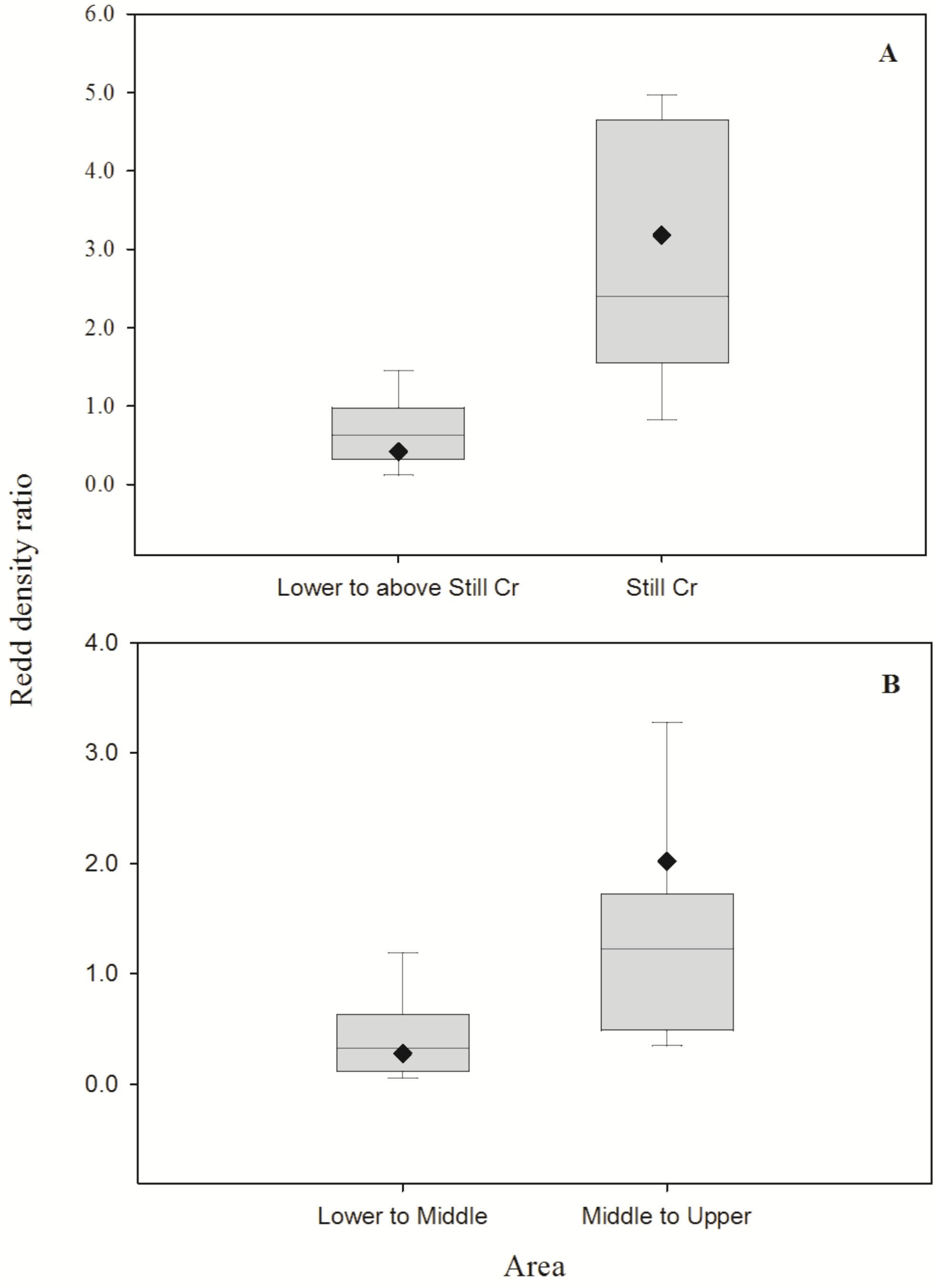

Figure 11. Ratio of redd density in the lower section of the Zigzag (A) and Salmon (B) rivers to redd density in upper areas of the watersheds in 2002–2010 (box plots) and 2012 (♦). Salmon River sections were: Arrah Wanna–mouth (lower), Arrah Wanna–Forest Road 2618 (middle) and Final Falls–Forest Road 2618 (upper). Zigzag River sections were: Still Creek–mouth (lower), Still Creek–Camp Creek including Camp Creek (above Still), and Still Creek. Horizontal lines within boxes denote medians, boxes encompass the 25th and 75th percentiles, and whiskers denote the 10th and 90th percentiles. Note different Y-axis scale.

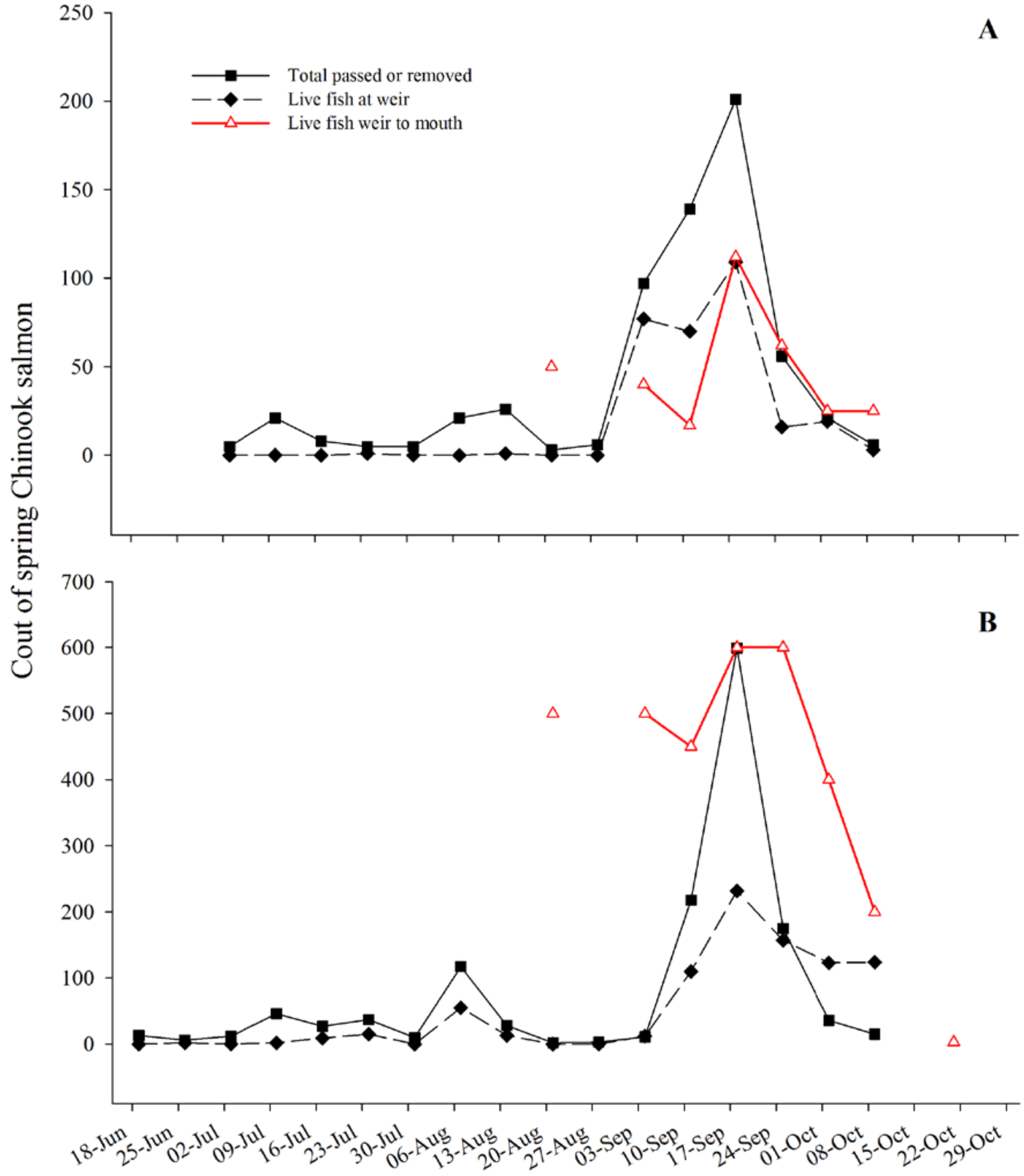

Figure 12. Adult spring Chinook salmon passed or removed at the weir, live fish counted in the immediate vicinity downstream of the weir (~ 100 ft), and weekly count of live fish in surveys downstream of weirs in the lower Zigzag (A) and Salmon (B) rivers, 2012. Note different Y-axis scale.

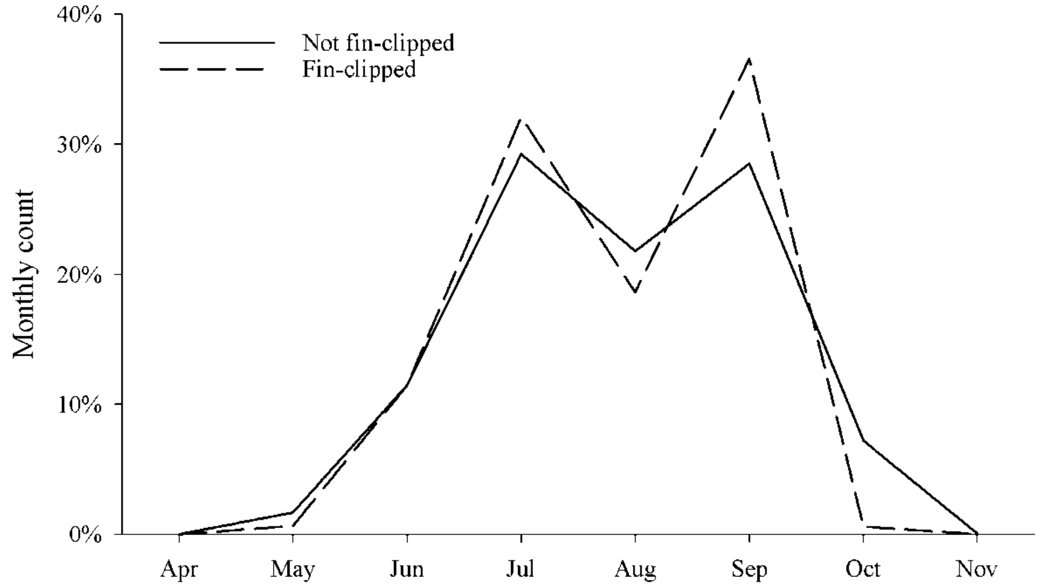

Figure 13. Run timing of fin-clipped and unclipped adult spring Chinook salmon at Marmot Dam on the Sandy River, 2002–2007.

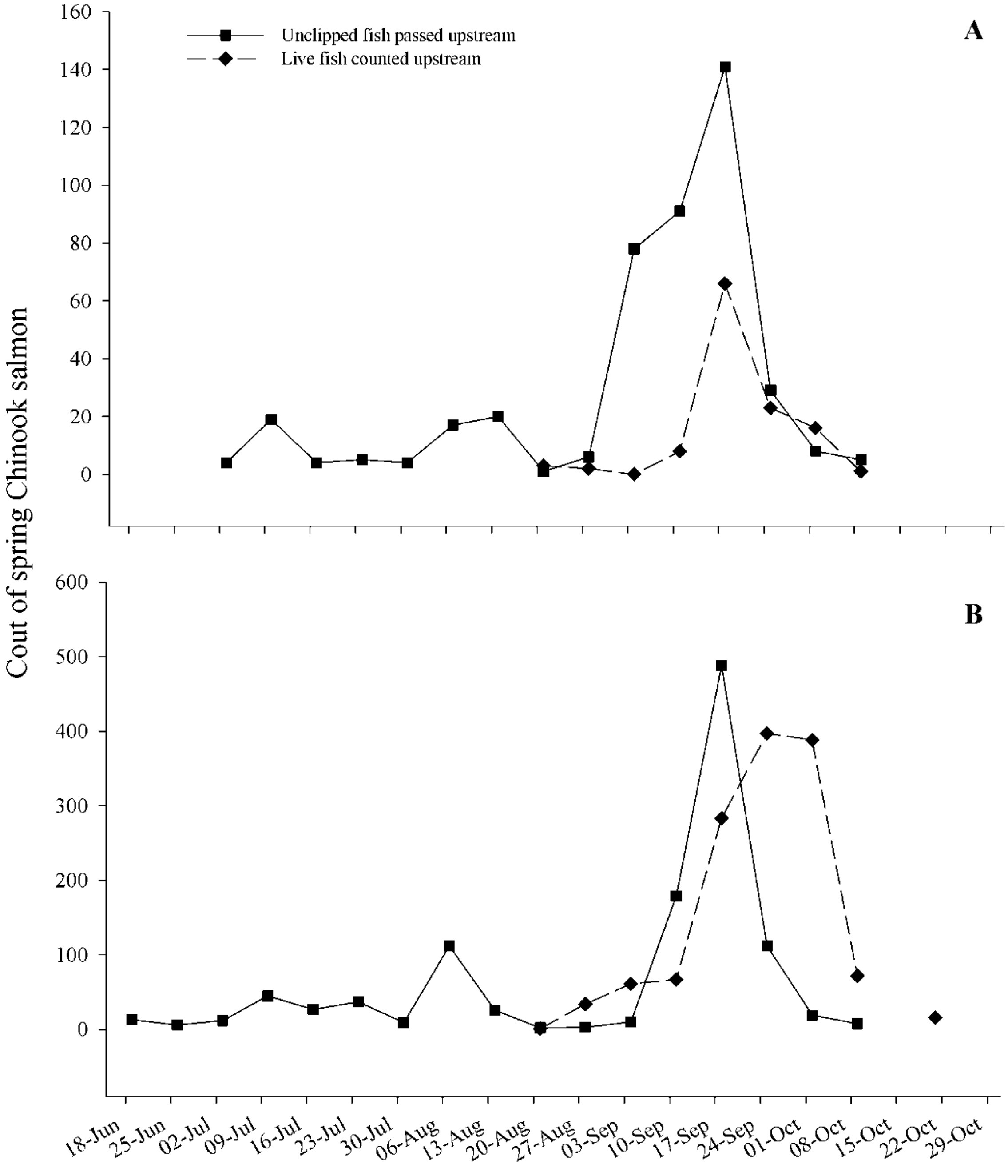

Figure 14. Adult spring Chinook salmon passed upstream of weirs (unclipped) and live fish counted in spawning surveys upstream of weirs in the Zigzag (A) and Salmon (B) river basins, 2012.

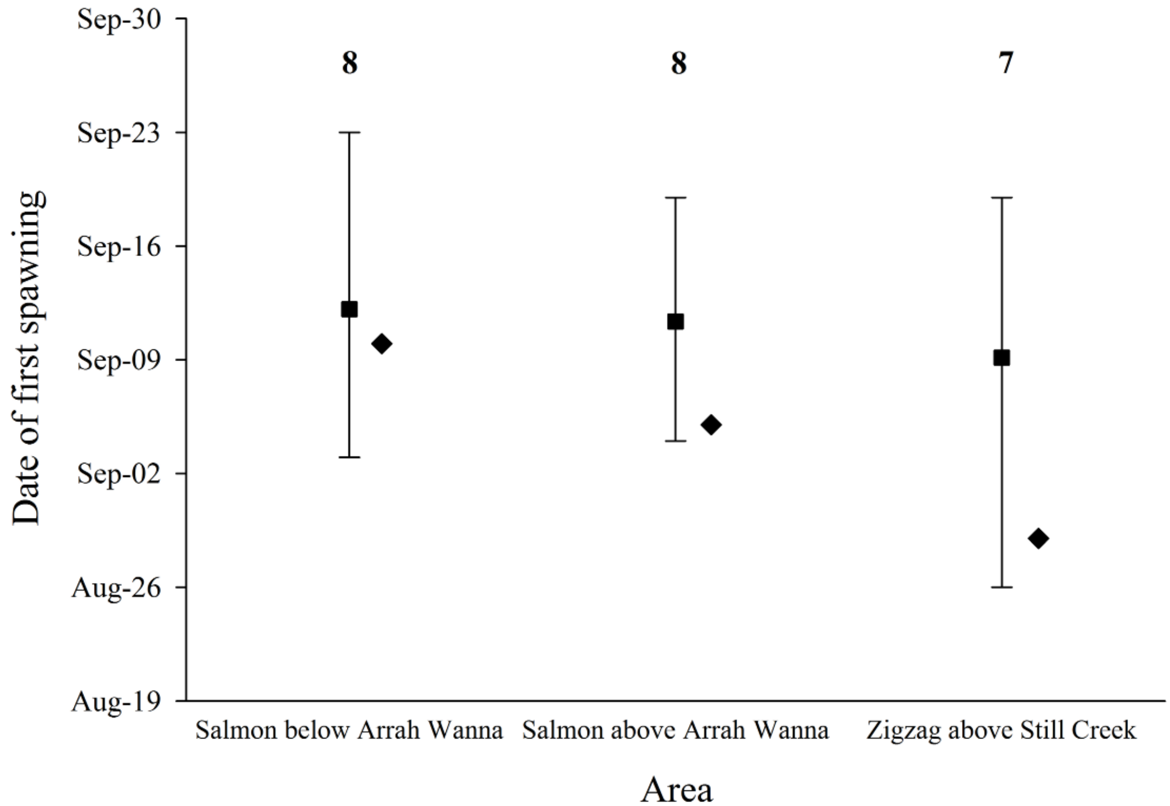

Figure 15. Date of first spawning for spring Chinook salmon in the Salmon and Zigzag River Basins for 2002–2009 (mean, ■), and in 2012 (♦). Data for 2010 were not included because surveys started late. Does not include 2003 for the Zigzag River Basin because surveys were more than two weeks apart between early and late September. The capped vertical lines are the range and the numbers above the lines are years in the data set.

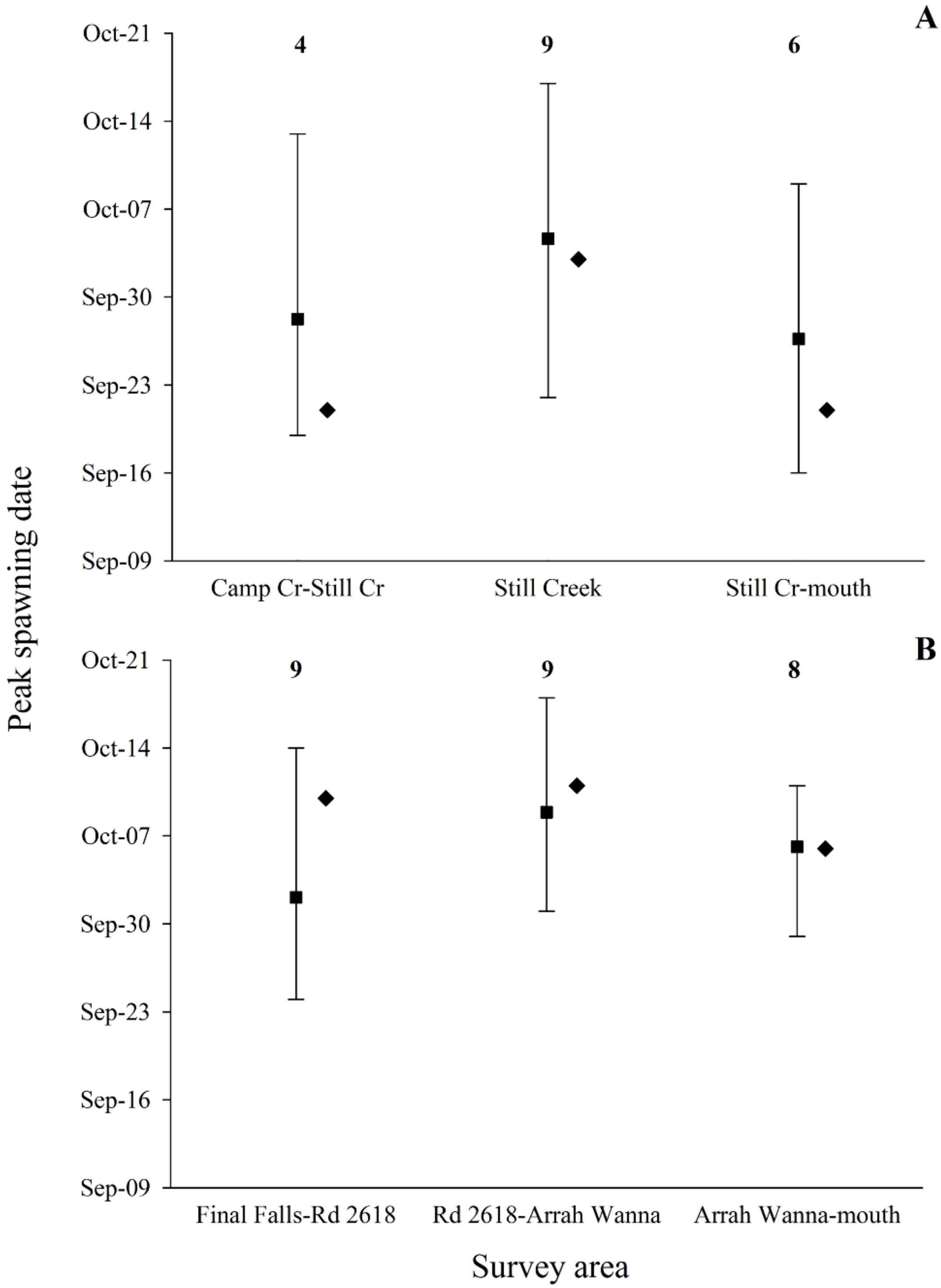

Figure 16. Peak spawning dates of spring Chinook salmon in the Zigzag (A) and Salmon (B) river basins in 2002–2010 (■) and in 2012 (♦). Capped vertical lines represent the range about the mean. The capped vertical lines are the range and the numbers above the lines are years in the data set. Years were excluded when only a single survey was conducted (Zigzag River) or when no late surveys were conducted (lower Salmon River).

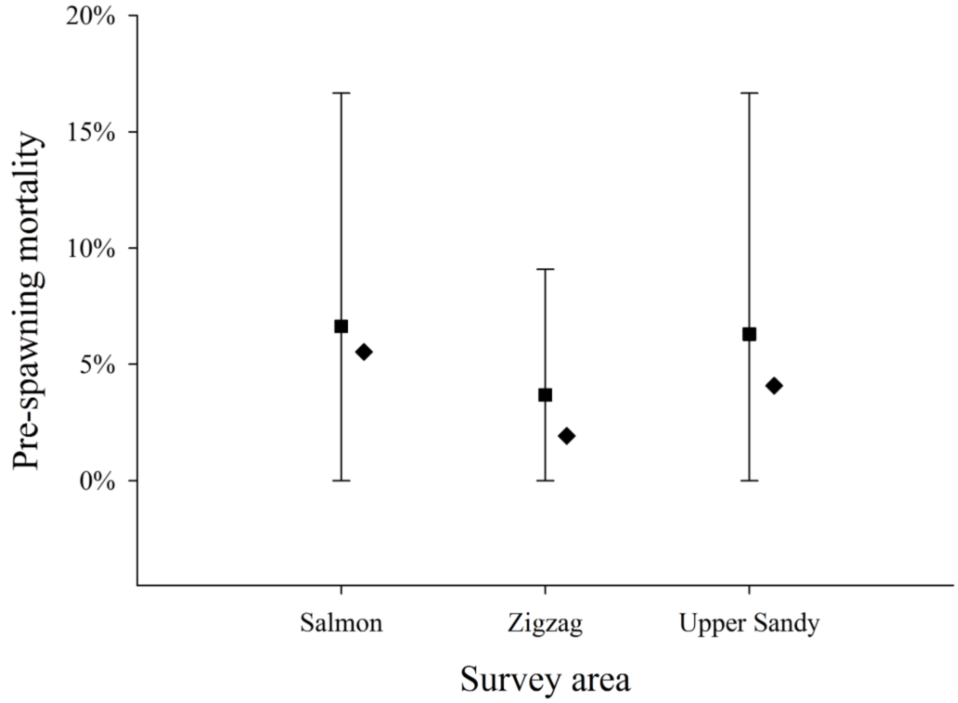

Figure 17. Pre-spawning mortality of wild spring Chinook salmon in the Salmon and Zigzag river basins, and in the upper Sandy River Basin in 2003–2009 (■) and 2012 (♦). The capped vertical lines represent the range about the mean.

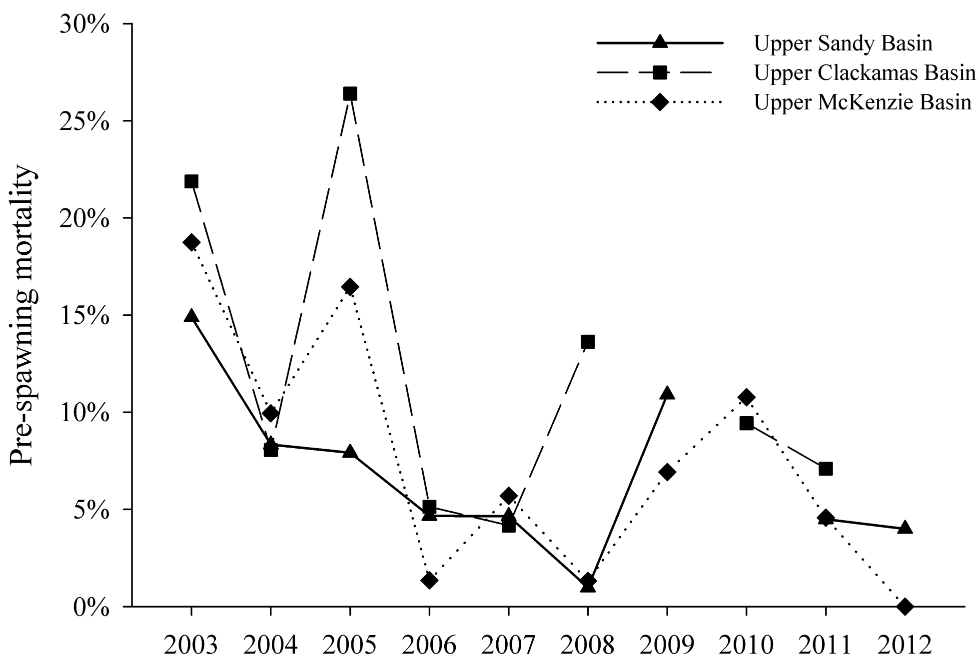

Figure 18. Pre-spawning mortality of wild spring Chinook salmon in the upper Sandy (▲), Clackamas (■), and McKenzie (♦) River Basins, 2003–2012. Does not include years when spawning surveys started in September.

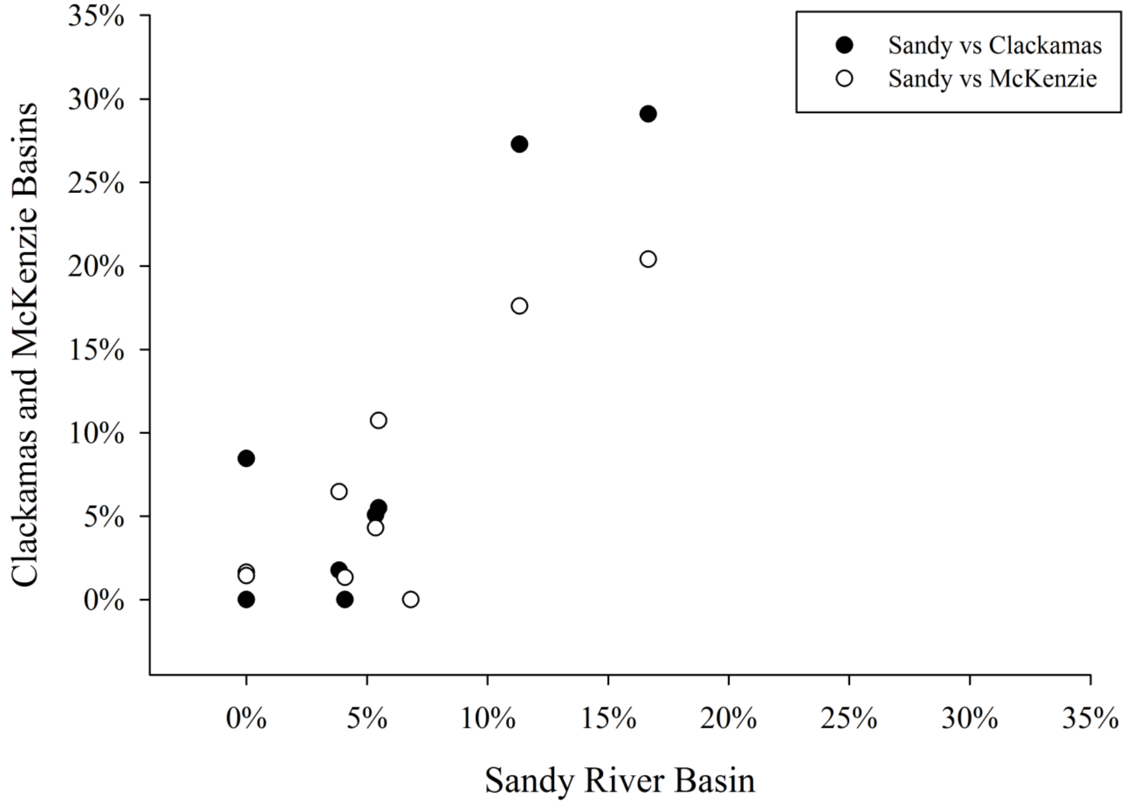

Figure 19. Relationship of pre-spawning mortality of unclipped spring Chinook salmon in the upper Sandy River Basin to that in the upper Clackamas and McKenzie river basins, 2003–2012. Does not include years when spawning surveys started in September.

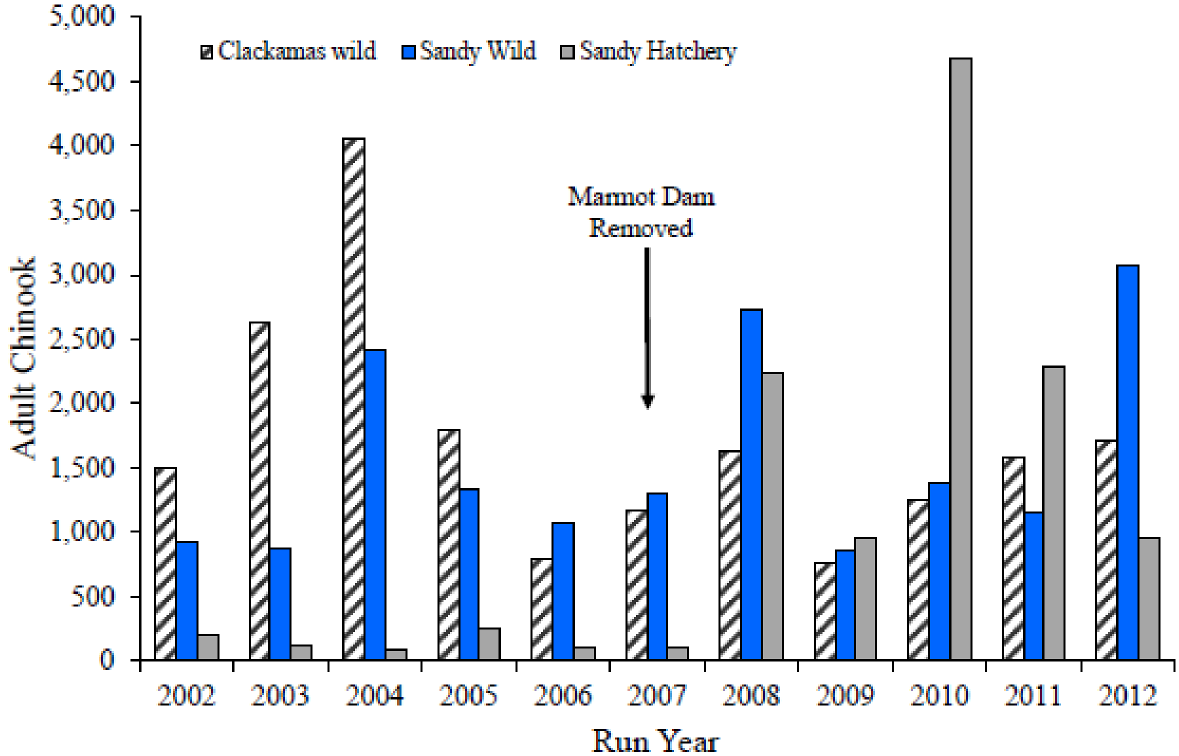

Figure 20. Estimated number of hatchery and wild spring Chinook salmon in the upper Sandy River Basin, and number of wild salmon in the Clackamas River Basin upstream of North Fork Dam, 2002–2012. Number of fish in the Sandy River Basin in 2008–2012 was estimated from redd counts and the relationship of dam counts to redd counts in 1996–1998 and 2002–2006. The proportion of wild and hatchery fish was estimated from recovery of carcasses. Wild fish in the Clackamas River in 2012 was estimated from counts of unclipped fish at the dam.

APPENDIX 1 – SUPPLEMENTAL DATA

Appendix Table 1. Potential spawning habitat for spring Chinook salmon in the Sandy River Basin with rankings for survey priority and quality of spawning habitat based on quantity or suitability of the substrate. Survey ranks are: 1 = highest priority, always done during every survey cycle; 2 = secondary spawning areas where low numbers of redds are usually observed, surveyed at least once during peak spawning period; 3 = low priority area with either very limited use or no documented use; surveyed occasionally but not every year, usually in years of high abundance. Quality ranks are based on professional experience of ODFW research biologists: 1 (highest quality) to 4 (lowest).

Stream	Reach	Length (mi)	Survey rank	Quality rank	Comments
Salmon River	Mouth to Final Falls	13.6	1	1	Excellent spawning habitat with highest number & density upstream of Forest Road 2618 (3.2 mi)
S Fork Salmon	Mouth to bridge	0.2	3	3.5	High gradient, large substrate, limited pockets of spawning gravel
Cheeney Creek	Mouth to high gradient section	2.0	2	3	Small stream, dependent on timed rain events in fall, probably increased use at higher spawner numbers
Boulder Creek	Mouth to high gradient section	0.5	3	3.5	Limited, flow dependent; infrequent spawning documented near mouth
Unnamed near Wildwood	Mouth to high gradient section	0.5	3	4	No documented use
Zigzag River	Mouth to Still Creek	2.2	1	1.5	Periodic large-scale gravel redistribution from floods; glacial sediment
Zigzag River	Still Creek to Camp Creek	2.2	1	2	Glacial sediment, bedload movement during high flows
Zigzag River	Camp Creek to Bridge 35	1.8	2	3	Glacial sediment, bedload movement during high flows, probably increased use at higher spawner numbers
Zigzag River	Bridge 35 to Lady Creek	1.9	3	3.5	High gradient, glacial sediment, limited spawning
Zigzag River	Lady Creek to Kiwanis Camp	0.4	3	4	High gradient, no documented use
Still Creek	Mouth to Cool Creek	3.3	1	1	Excellent spawning habitat; similar to upper Salmon River in spawner numbers & density
Still Creek	Cool Creek to Forest Road 2612	1.7	1	2	Recent restoration by Forest Service, probably increased use at higher spawner numbers
Still Creek	Above Forest Rd 2612	0.2	2	3	Small stream, likely limited use by spring Chinook except at higher spawner number and with adequate rainfall
Camp Creek	Mouth to Road 32 bridge	1.7	1	2	Pockets of spawning gravel, probably increased use at higher spawner numbers
Camp Creek	Road 32 bridge to Laurel Hill	1.7	3	3.5	Limited spawning gravel, some use at higher spawner numbers at downstream end of reach
Henry Creek	Mouth to high gradient section	0.6	3	4	Small stream, limited gravel, limited flow; no documented use
Devils Canyon Creek	Mouth to high gradient section	0.3	3	4	Small stream, limited gravel, limited flow; no documented use
Lady Creek	Mouth to high gradient section	.05	3	4	Small stream, limited gravel, limited flow; no documented use
Clear Creek	Mouth to E Barlow Road	0.5	2	3	Limited spawning near mouth, dependent on rainfall and gravel buildup at mouth by Sandy River deposits
Clear Creek	E Barlow Rd to powerlines	0.9	3	3.5	Limited spawning, low flow during spawning season, pockets of gravel

Appendix Table 1. Continued.

Stream	Reach	Length (mi)	Survey rank	Quality rank	Comments
Lost Creek	Mouth to Riley Campground	2.0	1	2	Pockets of spawning gravel, small stream
Lost Creek	Riley Campground to Lost Cr Campground	2.5	3	4	High gradient, limited spawning gravel, small stream, no documented use
Clear Fork Creek	Mouth to above bridge	0.6	1	2	Documented spawning in area near mouth and pockets of gravel; low gradient area upstream of bridge has small-diameter gravel more suitable for coho or steelhead
Muddy Fork Cr	Mouth to 2 mi upstream	2.0	3	4	Unstable area in glacial outwash plain, frequent channel changes & stream capture events with Sandy River, no documented use
Sandy River	Oxbow Park to Dodge Park	6.5	3.5	1.5	Good spawning gravel primarily used by fall Chinook
Sandy River	Dodge Park to Cedar Creek	3.2	3.5	2	Good spawning gravel but largely hatchery Chinook or fall Chinook; Sandy Hatchery is on Cedar Creek
Sandy River	Cedar Creek to Revenue Bridge	2.1	3.5	2	Good spawning gravel but largely hatchery Chinook or fall Chinook
Sandy River	Revenue Bridge to Marmot Dam	6.2	3	3	Approximately 1 mile below dam site has best spawning potential before entering gorge area that is dangerous to survey; river is still cutting & forming channel after dam removal
Sandy River	Marmot Dam to Marmot Bridge	6.4	2	2.5	Pockets of gravel upstream of Alder Creek Rapids; spawning potential has increased in some sections of old reservoir; river is still cutting & forming a channel
Sandy River	Marmot Bridge to Brightwood Bridge	1.9			Has not been surveyed, likely some limited spawning potential, difficult to survey because glacial melt limits visibility
Sandy River	Brightwood Bridge to Zigzag River	4.4	3	4	Surveyed once to look for potential and check for carcasses; high gradient, highly glacial, with bedload movement, frequent channel changes; difficult to survey because glacial melt limits visibility
Bull Run River	Mouth to dam	6.1	2	2.5	Pockets of spawning gravel for spring Chinook, mostly surveyed by Portland Water Bureau; overlap with fall Chinook
Little Sandy R	Mouth to Arrow Creek	4.8	3	2.5	Spawning potential but limited by flow in fall; use is dependent on stream rise with early fall rains in late September to mid-October

Appendix Table 2. Estimated spawning by wild spring Chinook salmon in the upper Sandy River Basin, 2002–2012. Origin of spawners was estimated by recovery of carcasses.

Basin, section	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
						Redds					
Salmon River:											
Final Falls–Forest Rd 2618	50	53	233	72	134	77	281	110	117	57	274
Forest Rd 2618–ArrahWanna	47	21	188	44	43	48	88	41	71	42	83
ArrahWanna–mouth	61	29	169	134	49	40	33	10	28	82	113
Zigzag River:											
Still Creek	51	22	100	58	104	28	178	59	125	71	253
Above Still Creek & Camp Cr	9	4	15	21	11	13	48	20	15	42	41
Still Creek–mouth	4	10	40	25	28	27	49	18	13	41	47
Other streams:											
Lost Creek	3	5	20	7	7	5	11	6	0	1	6
Clear Fork Creek	0	0	--	0	0	0	1	0	0	0	8
Clear Creek	0	0	0	0	2	0	0	0	0	--	--
TOTAL	**225**	**144**	**765**	**361**	**378**	**238**	**689**	**264**	**369**	**336**	**825**
						Redds/mi					
Salmon River:											
Final Falls–Forest Rd 2618	15.7	15.7	68.5	22.5	41.8	24.0	82.8	34.3	34.4	17.7	80.7
Forest Rd 2618–ArrahWanna	8.7	2.8	25.4	8.2	8.0	8.9	16.4	5.5	9.6	5.7	11.2
ArrahWanna–mouth	12.3	5.7	33.8	26.9	9.9	8.0	6.5	2.0	5.6	16.5	22.6
Zigzag River:											
Still Creek	15.4	4.5	30.2	11.5	31.6	8.5	35.6	11.8	23.9	14.2	50.7
Above Still Creek & Camp Cr	2.3	1.0	3.7	5.1	2.6	3.2	26.8	3.4	2.5	7.0	6.8
Still Creek–mouth	1.9	4.3	18.2	11.5	12.7	12.3	22.3	8.2	5.8	18.8	21.5
Other streams:											
Lost Creek	1.3	2.3	10.0	3.7	3.4	2.3	5.4	3.0	--	0.3	2.8
Clear Fork Creek	--	--	--	--	--	--	1.3	--	--	--	13.3
Clear Creek	--	--	--	--	3.0	--	--	--	--	--	--

Appendix Table 3. Estimated date of first and peak spawning of spring Chinook salmon in the Salmon and Zigzag river basins, 2002–2012.

	First spawning date				Peak spawning date			
	Salmon		Zigzag		Salmon		Zigzag	
	Above Wildwood	Below Wildwood	Above Still Cr	Below Still Cr	Above Wildwood	Below Wildwood	Above Still Cr	Below Still Cr
2002	Sep 11	a	Sep 12	a	Oct 7	Oct 10	Sep 27	c
2003	Sep 9	Sep 18	a	a	Oct 2	Oct 2	Sep 22	Sep 22
2004	Sep 7	Sep 7	Sep 8	a	Oct 6	Oct 12[b]	Oct 4	Sep 22[d]
2005	Sep 13	a	Sep 19	a	Oct 6	Sep 27	Sep 26	Sep 28
2006	Sep 11	Sep 12	Sep 12	a	Oct 15	Oct 10[b]	Oct 15	Sep 28
2007	Sep 12	a	Sep 10	Sep 10	Oct 5	Oct 4	Oct 5	Sep 27
2008	Sep 4	Sep 3	Aug 26	a	Oct 1	Oct 6	Oct 7	Oct 9
2009	Sep 9	Sep 16	Sep 8	Sep 10	Sep 28	Sep 22	Sep 23	Sep 22
2010	a	a	a	a	Oct 1	Sep 29	Oct 11	Sep 16[e]
2011	Sep 13	a	Sep 14	a	Oct 3	Oct 17	Oct 7	Oct 17
2012	Sep 5	Sep 12	Aug 29	Sep 5	Oct 13	Sep 28	Sep 28	Sep 21

[a] *Surveys begun late or numerous redds counted on first survey.*
[b] *Lower two sections combined (Wildwood–mouth and Arrah Wanna–Wildwood).*
[c] *Single survey conducted late.*
[d] *Single survey for season.*
[e] *Two additional surveys were within 5–8 redds of peak count.*

Appendix Table 4. Age composition (%) by return year of wild spring Chinook salmon in the Sandy River Basin. Origin of fish was determined by presence of the adipose fin and absence of induced thermal marks in otoliths.

Return year (n)	Age 3	Age 4	Age 5	Age 6
2002 (74)	0.0%	45.9%	51.4%	2.7%
2003 (40)	2.5%	25.0%	67.5%	5.0%
2004 (226)	0.4%	73.9%	25.2%	0.4%
2005 (162)	0.0%	23.5%	74.7%	1.9%
2006 (180)	1.1%	41.1%	56.7%	1.1%
2007 (216)	0.9%	23.1%	74.1%	1.9%
2008 (290)	0.3%	42.8%	54.8%	2.1%
2009 (91)	0.0%	41.8%	54.9%	3.3%
2010 (265)	4.9%	43.4%	51.3%	0.4%
2011 (242)	2.9%	58.7%	36.4%	2.1%
2012 (457)	0.4%	78.1%	19.3%	2.2%

Appendix Table 5. Age composition (%) by brood year of wild spring Chinook salmon in the Sandy River Basin. Origin of fish was determined by presence of the adipose fin and absence of induced thermal marks in otoliths.

Brood year (n)	Age 3	Age 4	Age 5	Age 6
1998 (62)	--	54.8%	43.5%	1.6%
1999 (70)	0.0%	14.3%	81.4%	4.3%
2000 (291)	0.3%	57.4%	41.6%	0.7%
2001 (145)	0.7%	26.2%	70.3%	2.8%
2002 (240)	0.0%	30.8%	66.7%	2.5%
2003 (214)	0.9%	23.4%	74.3%	1.4%
2004 (177)	1.1%	70.1%	28.2%	0.6%
2005 (180)	0.6%	21.1%	75.6%	2.8%
2006 (213)	0.0%	54.0%	41.3%	4.7%
2007 (435)	3.0%	32.6%	64.4%	--

APPENDIX 2

Functional Effect of Hatchery Spring Chinook Salmon in the Upper Sandy River Basin

Kirk Schroeder

Data on the proportion of hatchery origin spawners (pHOS) and the proportion of natural origin fish in hatchery broodstocks have been used to develop an index that estimates the influence of hatchery fish in a population (Mobrand et al. 2005). However, assessing the effect of hatchery fish in a population may require information about the geographical differences of pHOS within a population as well as the spatial distribution of hatchery spawners. Evaluations of hatchery fish in populations have included spatial distribution of spawning (Williamson et al. 2010; Matala et al. 2012), and homing or migration of returning hatchery fish (Johnson and Friesen 2013). The following analyses are intended to further assess the effect of hatchery spring Chinook salmon in the upper Sandy River Basin by evaluating the distribution of spawning within the upper basin, and estimating the influence of hatchery spawners within specific areas.

Methods

The proportion of hatchery origin spring Chinook salmon in the Sandy River Basin was estimated by the presence or absence of adipose fin clips in carcasses recovered during spawning surveys, and by presence or absence of induced thermal marks in otoliths recovered from carcasses without an adipose fin clip (or those with unknown fin clip status). Distribution of redds among survey sections was used to estimate the distribution of spawners in the basin. The number of spawners within geographic areas was estimated from redd counts and assumed a rate of 2.5 spawners per redd. Because the effect of hatchery spring Chinook salmon spawning in the basin is a factor not only of the proportion of hatchery origin spawners (pHOS) but also the location of spawning (distribution), I developed an index of hatchery influence based on pHOS within an area and the proportion of spawners (redds) in the basin that occurred within that area.

Values of the index increase as the potential influence of hatchery fish spawning in the river increases. Because the index is calculated from pHOS and the proportion of basin-wide redds occurring within an area, the response of the index to changes in these measures will depend on the changes in pHOS and spawning distribution relative to each other. For example, if pHOS and the proportion of redds within an area both increase the curve would be exponential (Appendix Figure 2-1(a)), whereas if the proportion of redds decreases relative to pHOS the curve would be an inverted U shape (Appendix Figure 2-1(b)).

I also calculated a second metric based on the ratio of hatchery origin spawners to natural origin (wild) spawners to describe the influence of hatchery spawners within geographic areas of the Sandy River Basin. The ratio provides a measure of the relative degree of potential interbreeding by assuming each hatchery fish will spawn with at least one wild fish, and assuming no differences in spawn timing or behavior. Ratios <1 indicate fewer hatchery spawners than wild spawners in the population and less risk of interbreeding, whereas values >1 indicate hatchery spawners are more numerous than wild spawners thus increasing the risk of interbreeding. An index of potential interbreeding within areas was estimated using the ratio and proportion of spawners in the basin that occurred within the areas.

Because current management actions include trapping and removing fin-clipped Chinook salmon at weirs in the Salmon and Zigzag River basins, I evaluated five areas as follows (abbreviations used in tables and figures are in parentheses):

1. Upper and mid Salmon River from Final Falls downstream to the Arrah Wanna survey section break (U Salmon),
2. Lower Salmon River from Arrah Wanna to the mouth (L Salmon),
3. Upper and mid Zigzag River from the upper section break to the Still Creek confluence, including Camp and Still creeks (U Zigzag),
4. Lower Zigzag River from Still Creek to the mouth (L Zigzag), and
5. Tributaries that included Lost, Clear Fork, and Clear creeks.

The indices were evaluated for times with different management of hatchery fish. Hatchery spring Chinook salmon returning in 2002–2007 were from releases that had been given adipose fin clips, and most fin-clipped adults were removed at Marmot Dam. We identified hatchery spawners with analysis of otoliths collected from carcasses without a fin clip. In 2008–2010, hatchery fish could freely migrate to the upper basin after Marmot Dam was removed. In 2012, weirs were installed in the lower Salmon and Zigzag rivers to trap and remove fin-clipped fish. Although weirs were also operated in 2011, they were installed late and the removal of fin-clipped fish was less complete than in 2012, therefore I excluded 2011 from the analyses.

I analyzed differences in pHOS among geographic areas and between periods with a two-way analysis of variance (ANOVA; area X period interaction), followed by pairwise comparisons. The distribution of spawning (proportion of spawning) among areas in the upper Sandy River Basin was analyzed first for all fish in 2002–2012, then for differences between periods in wild fish and for differences between wild and hatchery fish in 2008–2010. I used two-way ANOVA for these analyses (period X area and origin X area interactions). If an interaction effect was significant, I performed *t*-tests for each area to analyze period and origin effects on spawning distribution. I used a logit transformation for the analyses of spawning distribution if needed to normalize distributions or correct for unequal variances. Because the data included a small number of zero values, I used a modified logisitic transform by adding a small value to the numerator and denominator of the logit transform: $\ln((p+\varepsilon)/1-(p+\varepsilon))$, where ε is the minimum non-zero proportion (Warton and Hui 2011). Effect of origin on spawning distribution in 2002–2007 was not analyzed because sample size of hatchery fish was often small when fin-clipped fish were removed at Marmot Dam.

Results

As expected pHOS was significantly higher in 2008–2010 when spring Chinook salmon with fin clips could no longer be removed at Marmot Dam (Appendix Table 2-1 and Appendix Figure 2-2). Although results of ANOVA indicated a significant difference in pHOS among areas ($P = 0.2$), the only significant difference in pairwise comparisons was between upper Salmon and tributaries (Holm-Sidak test: $P = 0.009$), and comparison of areas within periods indicated no significant difference in pHOS ($P > 0.05$). The effect of trapping and removing fin-clipped fish in 2012 was most apparent in the upper-mid Salmon River and upper Zigzag River basins where pHOS in 2012 was near the 2002–2007 levels (Appendix Figure 2-2). Because the lower Salmon and Zigzag areas included sections upstream and downstream of weirs, the reduction in pHOS in

2012 was less than that in the upper areas and remained above the 2002–2007 levels, but was reduced from 2008–2010 levels. In tributaries pHOS remained at the 2008–2010 level in 2012.

Distribution of spawning for all fish in the upper Sandy River Basin was significantly different (Kruskal-Wallis one-way ANOVA; H = 46.94; $P < 0.001$), and significant differences were detected between some of the areas (Appendix Figure 2-3, Tukey test: $P < 0.05$). The highest percentage of spawning in the upper Sandy River Basin occurred in the upper areas of the Salmon and Zigzag River basins.

Distribution of spawning by hatchery and wild fish was similar within the periods before and after the removal of Marmot Dam (Appendix Figure 2-4). Although there was not a significant effect of origin on spawning distribution in 2008–2010, there were significant effects of area and origin X area interaction (Appendix Table 2-2). Within hatchery and wild fish, spawning distribution in 2008–2010 was significantly different between areas (Holm-Sidak test: $P < 0.05$) except upper Salmon and upper Zigzag (wild: $P = 0.91$; hatchery: $P = 0.22$) and lower Salmon and lower Zigzag (wild: $P = 0.82$; hatchery: $P = 0.13$), and additionally within hatchery fish between upper Salmon and lower Salmon ($P = 0.22$). The spawning distribution of hatchery and wild fish in 2008–2010 was significantly different within the areas of upper Salmon (*t*-tests: $P = 0.01$), lower Salmon ($P = 0.005$), and upper Zigzag ($P = 0.045$), but not within the lower Zigzag ($P = 0.29$) or tributaries ($P = 0.33$).

The spawning distribution of wild spring Chinook salmon was significantly different between 2002–2007 and 2008–2010 (Appendix Table 2-4 and Appendix Figure 2-4). There were also significant area effects and period X area effects for wild spawners. Within periods, spawning distribution of wild fish was significantly different between all areas except lower Salmon and upper Zigzag in 2002–2007 (Holm-Sidak test: $P = 0.97$), and in 2008–2010 between upper Salmon and upper Zigzag ($P = 0.11$) and lower Salmon and lower Zigzag ($P = 0.38$). At the 10% level of significance, the spawning distribution of wild fish was not significantly different between periods for the lower Zigzag (*t*-test: $P = 0.29$), but was for the other areas (upper Salmon: $P = 0.06$; lower Salmon: $P = 0.005$; Upper Zigzag: $P = 0.008$; tributaries: $P = 0.09$).

The index of hatchery influence (pHOS * proportion of spawning) was not significantly different among areas in 2002–2007 (Kruskal-Wallis one-way ANOVA; H = 7.94; $P = 0.09$), and *t*-tests within areas indicated significant differences between 2002–2007 and 2008–2010 except the tributaries ($P = 0.43$) (Appendix Figure 2-5). The change in the index between periods was highest for the upper Salmon and upper Zigzag areas, which is because they had a higher proportion of spawning than other areas. In contrast with pHOS, the hatchery influence index suggested a smaller effect of hatchery fish in 2008–2010 in the lower Salmon and lower Zigzag areas (Appendix Figures 2-2 and 2-5). The index in 2012 was lower than the mean in 2008–2010 for all areas except the tributaries, and was at the 2002–2007 level in the upper Salmon.

The ratio of hatchery to wild spawners was generally highest in 2008–2011, although the highest year varied among areas (Appendix Table 2-4). As a baseline, the index of potential interbreeding (H:W ratio * proportion of spawning) was not significantly different among areas in 2002–2007 (one-way ANOVA; $F_{4,25} = 1.96$; $P = 0.13$). Within areas, *t*-tests indicated significant differences between 2002–2007 and 2008–2010 for all areas except the tributaries ($P = 0.07$) (Appendix Figure 2-6). In contrast with the hatchery influence index, the interbreeding index suggested a larger effect of hatchery fish in the lower Salmon area (Appendix Figures 2-5 and 2-6). In 2012, the index was at or near the 2002–2007 levels for all areas except the tributaries.

The performance of the two indexes relative to pHOS depended on factors such as spawning distribution and the composition of the spawning population within an area. The trend indicated by the indexes was similar to that estimated from pHOS for the upper Salmon and upper Zigzag areas, but in the other areas the indexes suggested a lower effect of hatchery spawners than pHOS (Appendix Figures 2-7 and 2-8). For example, despite high levels of pHOS in the tributaries, the indexes remained relatively low because a small percentage of spawning occurred in these streams. The exception was a peak in the interbreeding index in 2011, primarily because the hatchery to wild ratio was 63:1 (103 hatchery: 2 wild) (Appendix Figure 2-8).

Management actions in the upper Sandy River Basin, such as removing fin-clipped fish at traps and acclimating smolts in the Bull Run River, will likely have more effect on pHOS than on distribution of spawners among spawning areas. In areas with a higher proportion of spawners, actions to reduce pHOS will have a larger numerical effect on the index of hatchery influence than in areas with a lower proportion of spawners (Appendix Figure 2-9). For example, in an area where the proportion of spawners was 30% and pHOS was 30%, actions to reduce pHOS to 10% would result in a decrease in the hatchery influence index from 0.09 to 0.03, which is similar to the mean for the upper Sandy River Basin in 2002–2007.

Discussion and Summary

With the removal of Marmot Dam, fin-clipped spring Chinook salmon could freely access the upper Sandy River Basin and pHOS increased significantly. However, pHOS did not differ among areas before or after the removal of the dam, indicating that hatchery fish were spatially dispersed. Although pHOS was similar among areas, the effect of hatchery fish spawning in the upper basin varied because of differences in spawning distribution. The spawning distribution of wild spring Chinook salmon changed before and after the removal of Marmot Dam, particularly with increased spawning in the upper Salmon and Zigzag River basins, and decreased use of the lower Salmon River.

Removal of Marmot Dam may have altered the run timing of spring Chinook salmon into the upper Sandy River Basin because fish would no longer be falsely attracted to the Bull Run River or delayed at the dam. If adult salmon arrived earlier in the upper basin, migration to the upper reaches of the Salmon and Zigzag River basins may have increased. In addition, spring Chinook salmon migrating later in summer when glacial melt produces high sediment loads in the Sandy and Zigzag rivers might have been attracted to the Salmon River because it would have been the first, large stream with clear water the fish would have encountered upstream of Marmot Dam. Consequently, spawning in the Zigzag River Basin may have increased after the dam was removed because earlier migrants could migrate farther upstream without being affected by the effects of glacial melt.

Analysis indicated that assessing the potential impact of hatchery spawners could be improved by including data on spatial distribution of spawning and the ratio of hatchery to wild spawners within areas, in contrast to using the single metric of pHOS. These analyses also confirmed the strategy of trapping and removing fin-clipped fish in the Salmon and Zigzag basins for reducing the number and percentage of hatchery origin spawners because these areas support the highest number of spawners. As a result, all measures of hatchery influence were lower in 2012 than in 2008–2010, and for most areas were at or near levels in 2002–2007.

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TABLES AND FIGURES: APPENDIX 2

Appendix Table 2-1. Two-way ANOVA results comparing pHOS of spring Chinook salmon in 2002–2007 and 2008–2010 for five areas of the upper Sandy River Basin, and effects of period and area.

Source	Sum of squares	df	Mean squares	*F*-ratio	*P*
Period	1.899	1	1.899	82.483	< 0.001
Area	0.307	4	0.077	3.331	0.021
Period X Area	0.072	4	0.018	0.780	0.546
Error	0.806	35	0.071		

Appendix Table 2-2. Two-way ANOVA of the logit transformed spatial distribution of spring Chinook salmon in the upper Sandy River Basin in 2008–2010 and effects of origin and area.

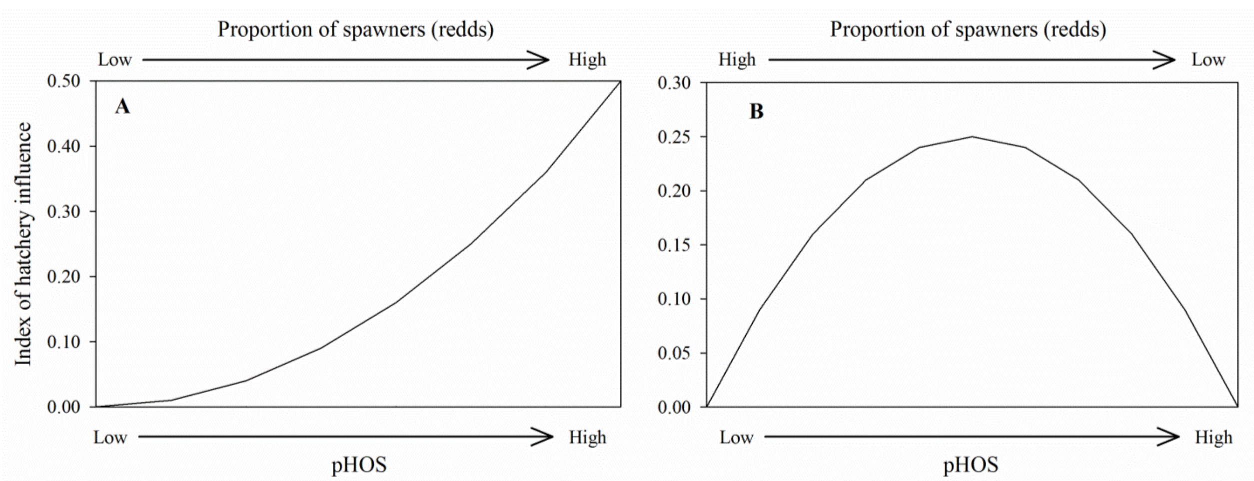
Source	Sum of squares	df	Mean squares	*F*-ratio	*P*
Origin	0.806	1	0.806	2.128	0.160
Area	69.053	4	17.263	45.568	< 0.001
Origin X Area	4.964	4	4.964	3.276	0.032
Error	7.577	20	0.379		

Appendix Table 2-3. Two-way ANOVA of the logit transformed spatial distribution of wild spring Chinook salmon in the upper Sandy River Basin and effects of period and area.

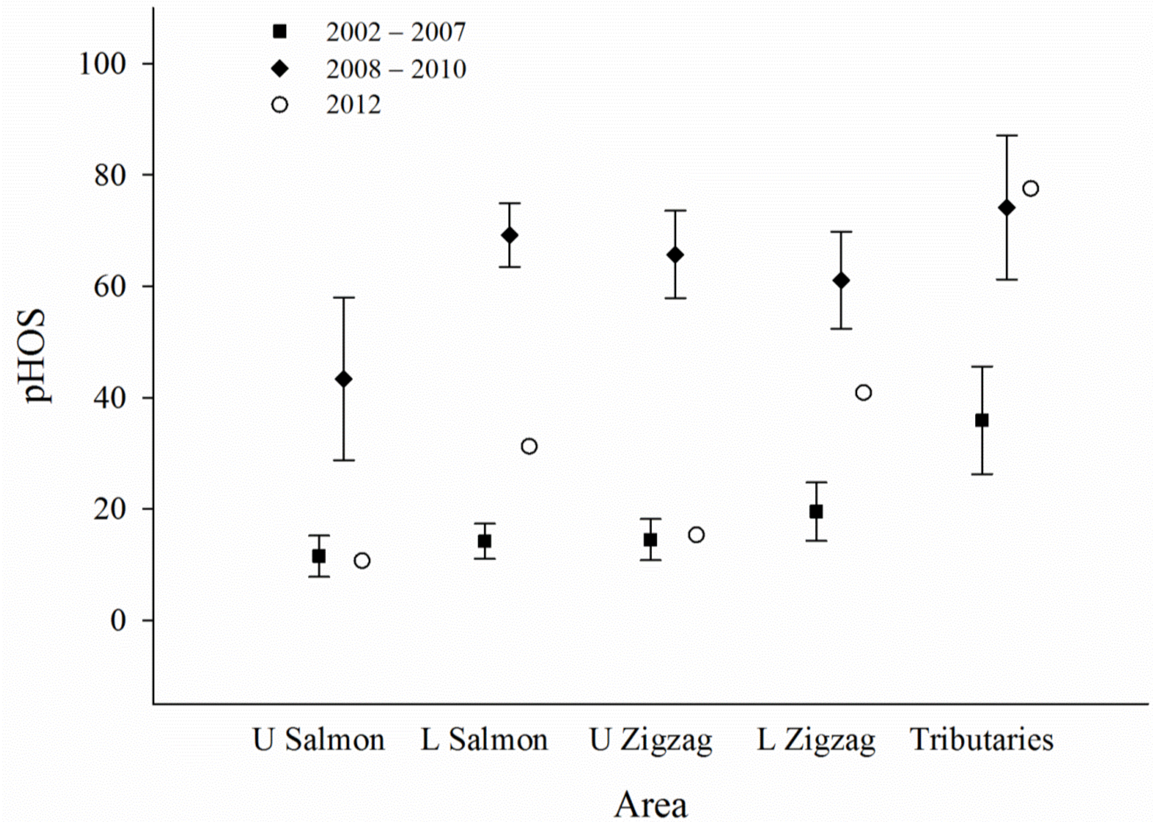
Source	Sum of squares	df	Mean squares	*F*-ratio	*P*
Period	1.651	1	1.651	5.601	0.024
Area	83.015	4	20.754	70.409	< 0.001
Period X Area	8.612	4	2.153	7.304	< 0.001
Error	10.317	35	2.348		

Appendix Table 2-4. Number of hatchery origin spring Chinook salmon relative to natural origin fish in the spawning population within five areas of the upper Sandy River Basin, 2002–2012.

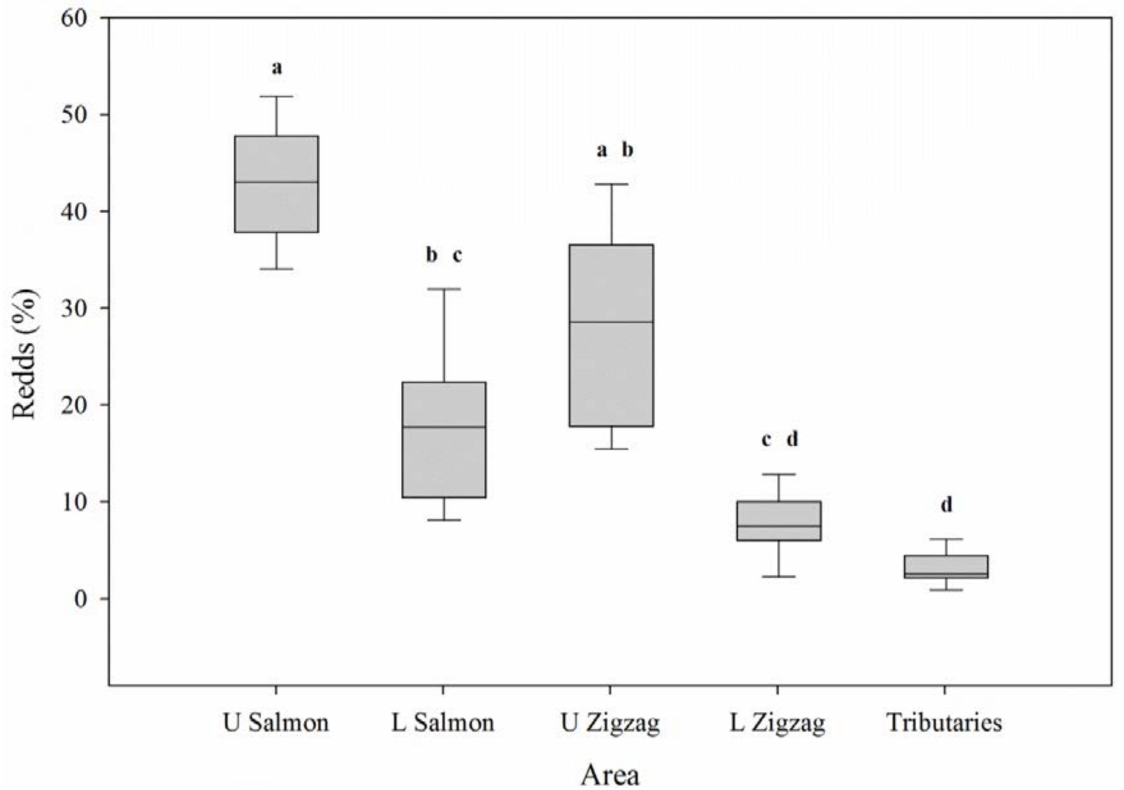
	Hatchery origin spawners relative to wild spawners within—				
Year	U Salmon	L Salmon	U Zigzag	L Zigzag	Tributaries
2002	0.20	0.11	0.19	0.18	1.33
2003	0.16	0.27	0.05	0.33	0.00
2004	0.00	0.04	0.06	0.20	0.00
2005	0.25	0.09	0.27	0.24	0.50
2006	0.02	0.25	0.09	0.23	0.33
2007	0.06	0.44	0.00	0.00	1.00
2008	0.56	3.81	1.12	1.22	1.59
2009	0.24	7.17	1.72	1.00	0.61
2010	2.64	5.00	3.80	3.63	25.00
2011	2.28	0.96	1.33	1.96	63.31
2012	0.14	0.48	0.20	0.69	4.10



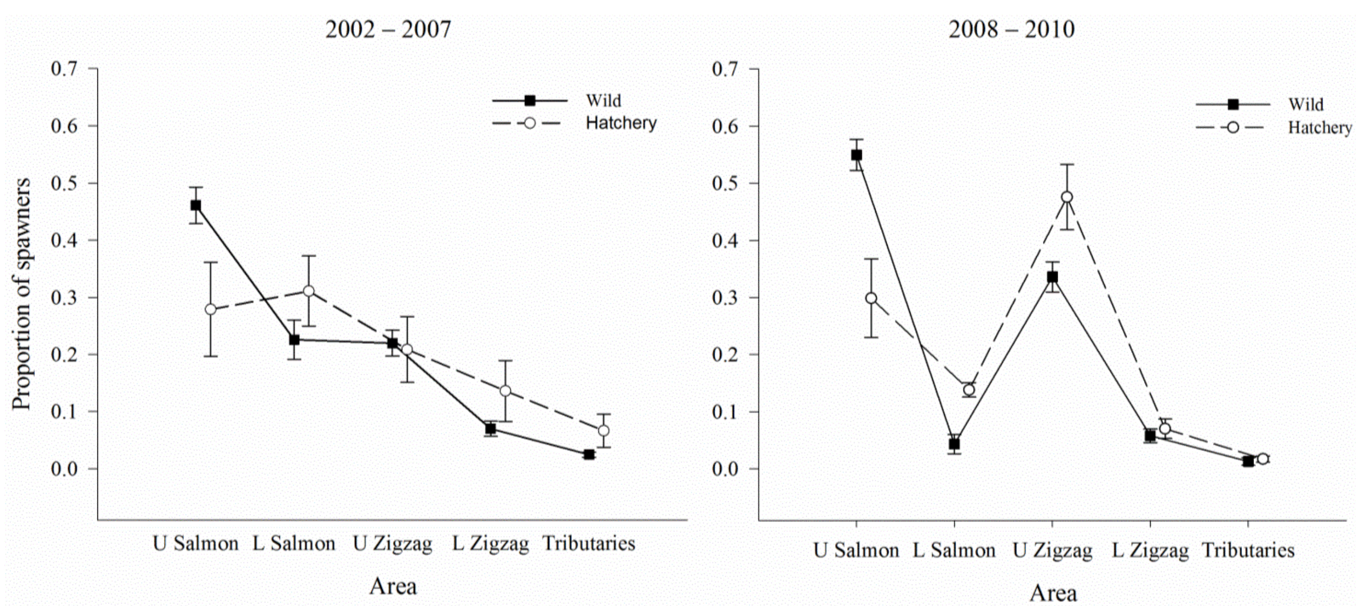
Appendix Figure 2-1. Effect on the hatchery influence index of the relationship between the proportion hatchery origin spawners (pHOS) and the proportion of spawners (redds) in a basin that occur within a geographic area, showing the proportion of spawners changing in the same direction as pHOS (A) or in the opposite direction (B). Note different Y-axis scales.



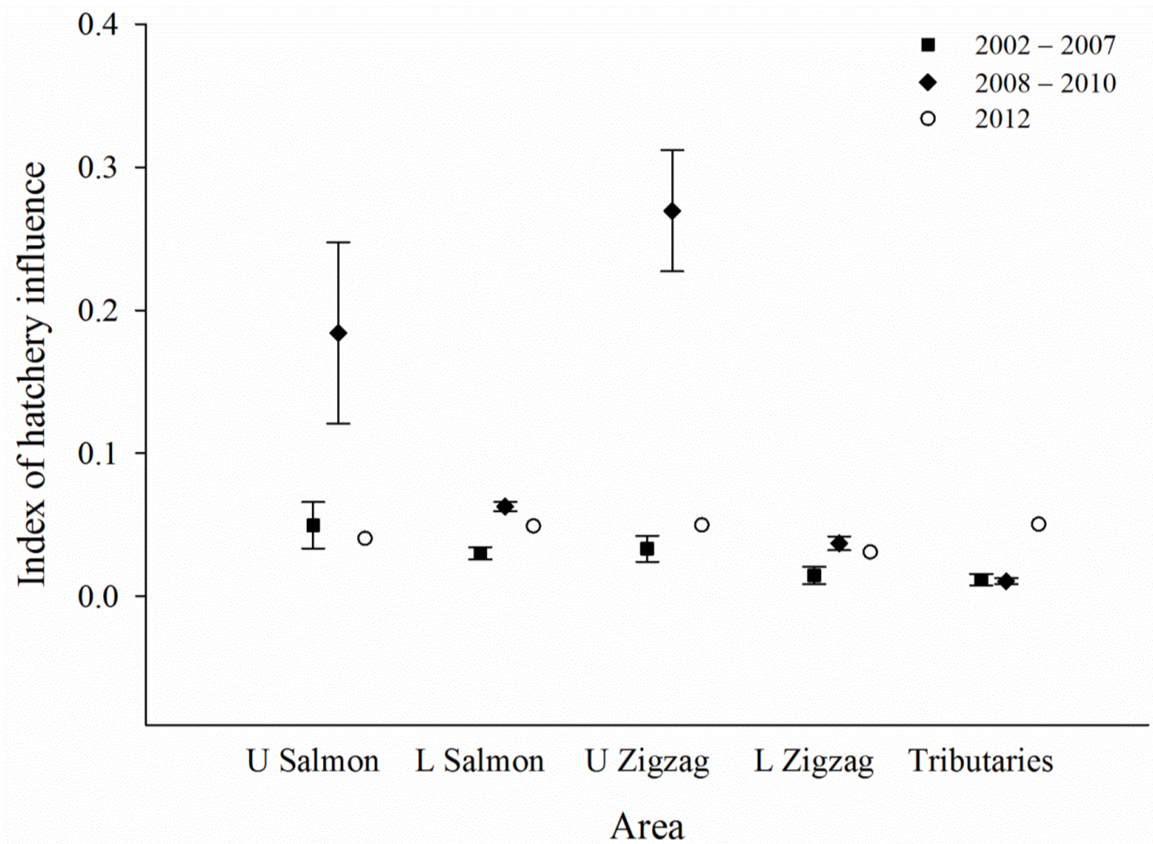
Appendix Figure 2-2. Mean (± SE) percentage of spring Chinook salmon spawners that were hatchery origin (pHOS) in five areas of the upper Sandy River Basin, 2002–2007 (■) and 2008–2010 (♦), and the percentage in 2012. Origin of spawners was determined by presence of an adipose fin clip or presence of induced thermal marks in the otoliths of unclipped fish. *See* text for definition of areas.



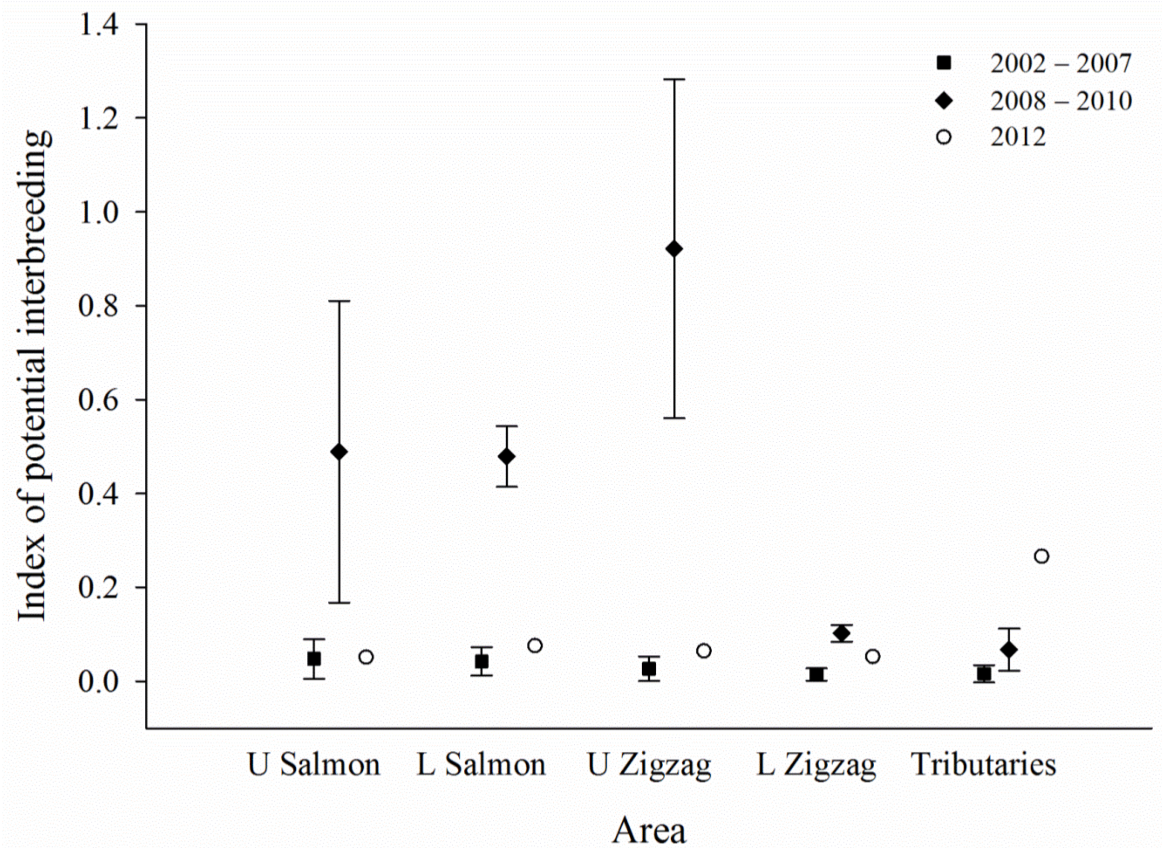
Appendix Figure 2-3. Distribution of redds in five areas of the upper Sandy River Basin, 2002–2012. Horizontal lines within boxes denote medians, boxes encompass the 25th and 75th percentiles, and whiskers denote the 5th and 95th percentiles. Different lowercase letters indicate significant differences (*P* < 0.05; Tukey test). *See* text for definition of areas.



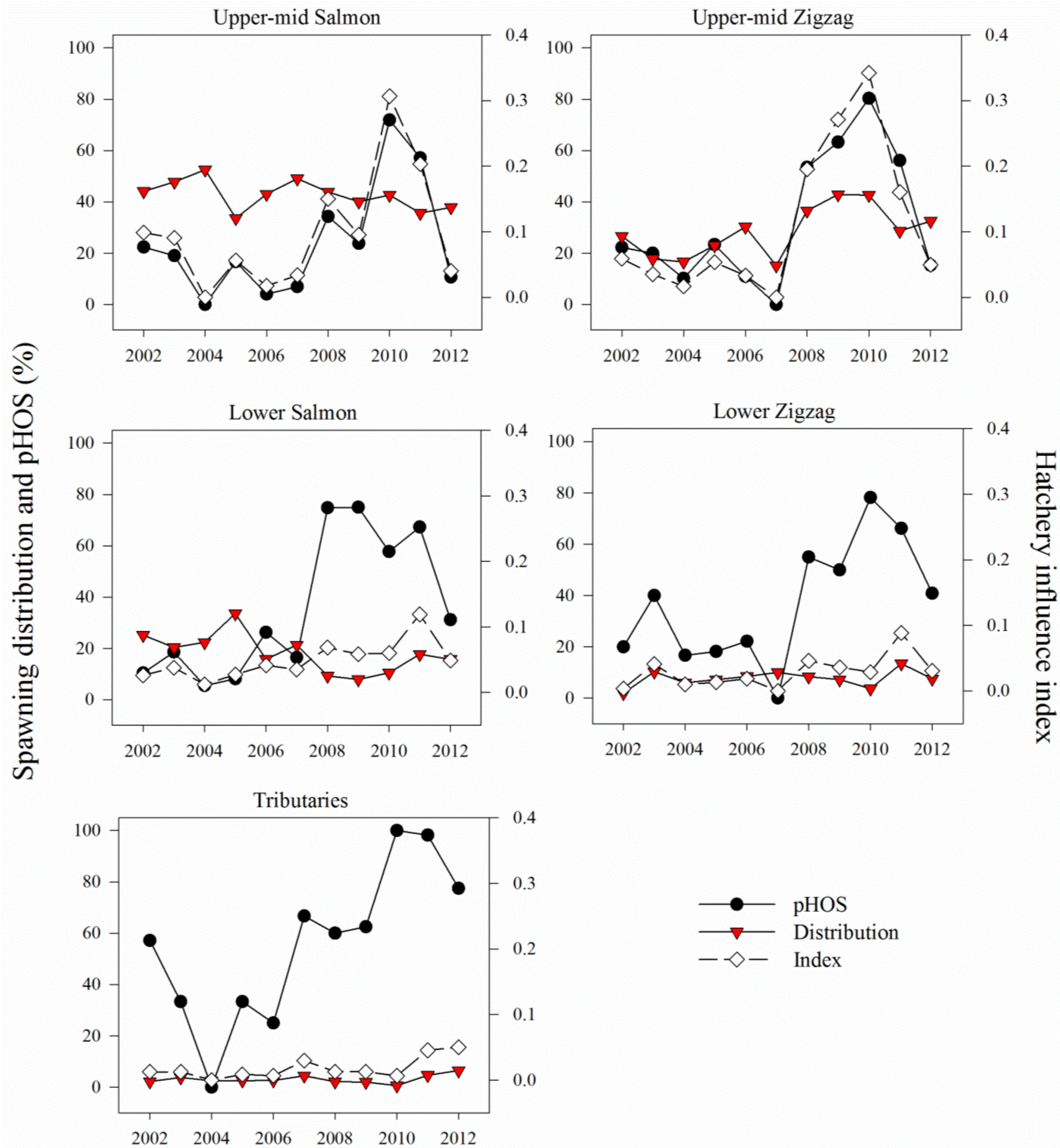
Appendix Figure 2-4. Mean (± SE) distribution of spawning by wild and hatchery spring Chinook salmon in five areas of the upper Sandy River Basin, 2002–2007 and 2008–2010. *See* text for definition of areas.



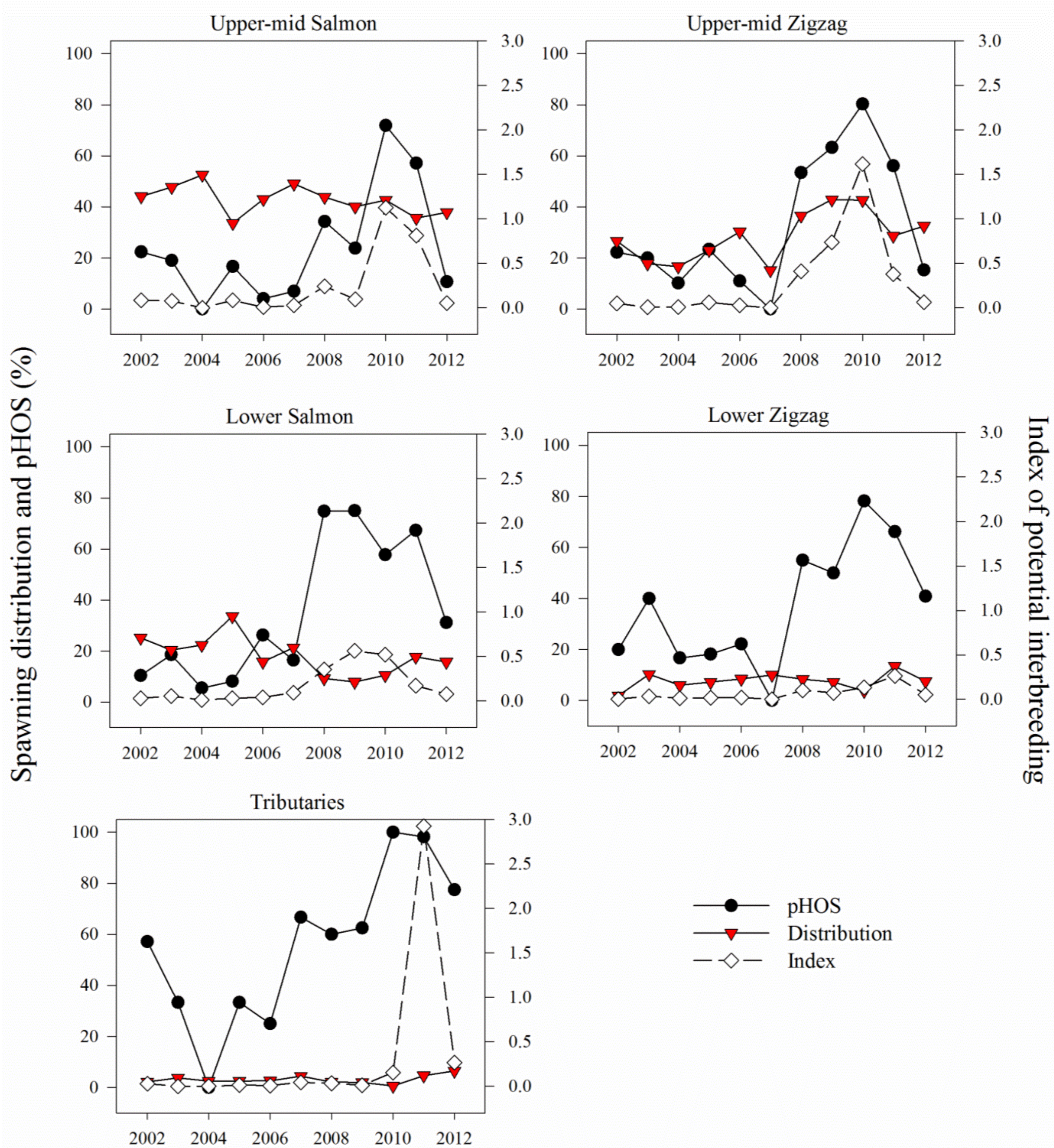
Appendix Figure 2-5. Mean (± SE) index of hatchery influence (pHOS * proportion of spawning) for spring Chinook salmon within five areas of the upper Sandy River Basin, 2002–2007 (■) and 2008–2010 (♦), and the index in 2012. *See* text for definition of areas.



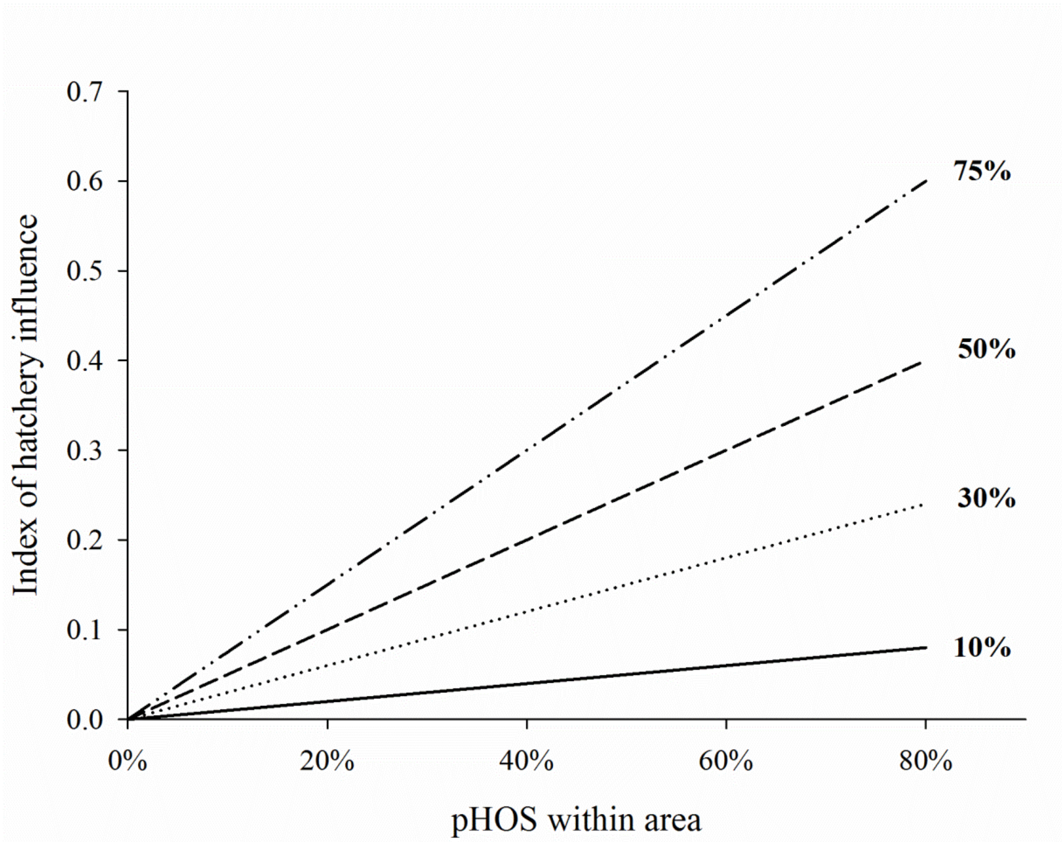
Appendix Figure 2-6. Mean (± SE) index of potential interbreeding between hatchery and wild spring Chinook salmon (H:W ratio * proportion of spawning) within five areas of the upper Sandy River Basin 2002–2007 (■) and 2008–2010 (♦), and the index in 2012. *See* text for definition of areas.



Appendix Figure 2-7. Relative trends in spawning distribution, pHOS (left Y axis), and an index of hatchery influence (pHOS * distribution; right Y axis) for five areas of the upper Sandy River Basin, 2002–2012. *See* text for definition of areas.



Appendix Figure 2-8. Relative trends in spawning distribution, pHOS (left Y axis), and an index of potential interbreeding between hatchery and wild spring Chinook salmon (H:W ratio * proportion of spawning; right Y axis) for five areas of the upper Sandy River Basin 2002–2012. *See* text for definition of areas.



Appendix Figure 2-9. Effect of changes in pHOS within an area of a watershed on the index of hatchery influence at four levels of spawner distribution within an area.