Comparing the Reproductive Success of Yakima River Hatchery and Wild-Origin Spring Chinook

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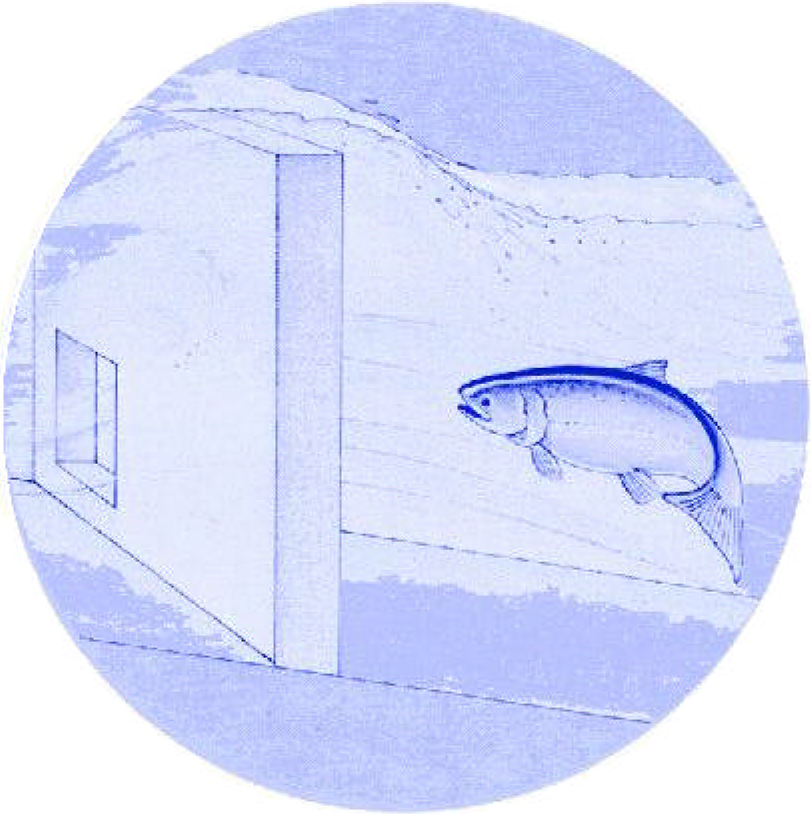

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Comparing The Reproductive Success Of Yakima River Hatchery- And Wild-Origin Spring Chinook

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SUMMARY

In the Yakima Spring Chinook supplementation program, wild fish are brought into the Cle Elum Hatchery, artificially crossed, reared, transferred to acclimation sites, and released into the upper Yakima River as smolts. When these fish mature and return to the Yakima River most of them will be allowed to spawn naturally; a few, however, will be brought back to the hatchery and used for research purposes. In order for this supplementation approach to be successful, hatchery-origin fish must be able to spawn and produce offspring under natural conditions. Recent investigations on salmonid fishes have indicated that exposure to hatchery environments during juvenile life may cause significant behavioral, physiological, and morphological changes in adult fish. These changes appear to reduce the reproductive competence of hatchery fish. In general, males are more affected than females; species with prolonged freshwater rearing periods are more strongly impacted than those with shorter rearing periods; and stocks that have been exposed to artificial culture for multiple generations are more impaired than those with a relatively short exposure history to hatchery conditions.

A key question that the Yakima Fish Supplementation Project is designed to address is whether the spring chinook produced by the Cle Elum Hatchery have had their reproductive competence affected by the fish cultural regimes they experienced. In 2000, an observation stream (spawning channel) was built adjacent to the Cle Elum Hatchery. The stream is being used to compare the reproductive success of hatchery- and wild-origin spring chinook reproducing in a quasi-natural setting. The channel is 127 m long by 7.9 m wide and is laid out in the shape of a “U.” It is subdivided into seven sections by concrete cross weirs. Spawning gravel from a local quarry was imported into the stream and water from the hatchery’s raceways is pumped into the stream when adult salmon, their eggs, and newly emerged fry are present.

Direct reproductive comparisons between hatchery- and wild-origin fish were not possible until 2001 when the first hatchery adults produced by the project returned to the Yakima River. During the period covered by this report, only wild spring chinook were available. However, these fish provided us with an important opportunity to refine how the observation stream should be operated. Consequently, in 2000 we filled two 15 m long by 7.9 m wide channel sections with wild spring chinook to: 1) refine fish handling and tagging procedures, 2) evaluate how physical conditions in the stream affected adult distribution patterns, 3) ascertain whether the methods developed to monitor and record environmental conditions in the observation stream provided an adequate overview of the physical conditions the adults and their offspring experienced in stream, 4) develop and test behavioral observation techniques 5) examine the effects of different instantaneous spawner densities on the ability of the fish to reproduce, and 6) determine what the egg-to-fry survival rate might be in the stream.

The techniques used to select which fish were placed into the stream, how they were weighed, measured, tagged, and DNA sampled all proved to be relatively non-stressful. For example, many of the fish spawned within hours after being placed into the stream

and their reproductive behavior was very similar to what has been observed in wild fish spawning in the upper Yakima River. Previous work done on naturally spawning spring chinook indicated that they prefer to spawn in 30 to 90 cm/sec flows and 24 cm or deeper water. Water flows in the stream were systematically recorded before adults were placed into the stream and after spawning had taken place. About 50% of the area in each section contained flow and depth characteristics preferred by spring chinook. Other portions had slower flows that could be used for resting areas and also some zones of very rapid flow. We found that the females established their redd locations in areas where flows equaled 38 to 61 cm/sec. The last females to establish redds in the high-density section did so in higher velocity areas than the fish that had already acquired territories. In general, water velocities decreased from the head end of a section to its end. The first locations of each section that were selected as redd sites occurred at the very end of each section. These sites had optimal flows and were reminiscent of the pool riffle interface areas that occur in natural streams.

The gravel placed in the stream had a Fredle index value of around 7 and was easily moved by the females. A gravel mixture having a Fredle index of 22 was requested, however, the material used had more fines than specified. In retrospect, the spawning bed materials imported into the stream turned out to be more appropriate for our experimental purposes because females will have to thoroughly clean the gravel in their nest sites to obtain high egg-to-fry survival rates. Hence, if differences exist between the ability of hatchery and wild females to clean the gravel in their nests then disparities in egg-to-fry survival rates should occur. This may not have happened if our original gravel recipe had been employed. Since, the water used to run the observation stream originates from the hatchery's raceways, sand and organic sediments are continually being imported into the stream. Gravel samples were taken before any fish were placed into the observation stream and also collected after fry emergence had been completed. When the gravel was first placed into the stream it had a Fredle index of around 11. After emergence was complete this index was reduced to approximately 7, indicating that more fines had been introduced. Consequently, the gravel was cleaned prior to placing adults into the structure in 2001. The cleaning process reduced the quantity of fines but did not appreciably raise the Fredle value. However, for the reasons given above the gravel mixture currently in the stream is fulfilling our experimental objectives.

Water temperatures were recorded once every two hours throughout the spawning and incubation period. Seasonal changes in temperature occurred but no differences were observed between temperatures taken in the water column and those that were obtained from temperature probes that had been buried 30 cm below the gravel surface. In summary, the physical conditions in the stream, water velocity, depth, gravel composition, and temperature, were all similar to those that have been observed in natural spawning sites used by spring chinook. The procedures developed in 2000 to create these conditions were repeated in 2001 and again in 2002 when fish were placed into the stream and allowed to spawn.

Both scan and focused behavioral observations were made on the fish while they spawned in the observation stream. These observations revealed that the social status of the fish could be discerned by examining their nuptial color patterns. Three general patterns, one referred to as “stripe”, another as “gold”, and the last as “black” were observed. Gradations between these patterns clearly exist and the fish are capable of quickly changing from one pattern to the next. Territorial females and sub-dominate males usually had the stripe pattern, dominate males generally possessed the black pattern, while non social or wandering fish of both sexes typically had the gold pattern. Our observations also indicated that large differences in the reproductive behavior of the males placed in the sections existed. Some individuals participated in many spawings while others apparently never spawned. Precocial males invaded the stream sections and one was observed spawning with a female and a larger male. A DNA pedigree analysis made on fry sampled from each section indicated that our behavioral observations coincided with male reproductive success. That is, those individuals that appeared behaviorally dominate fathered most of the fry produced from a section. This same analysis showed that the precocial males had fathered some of the fry collected from both sections. Moreover, the behavioral observations and the DNA pedigree work indicated that variation in female reproductive success was much lower than that seen in males. All the females placed in the sections were observed to produce offspring while that was clearly not the case for the males.

In addition, we discovered that placing 8 females (8 m^2/female) produced enough intra-sexual competition among the fish to reduce redd sizes and induce some egg retention. In the section with a lower instantaneous density (17 m^2/female) redd sizes were two to three times as large and egg retention was relatively low. One of our experimental goals is to induce competition among females when wild and hatchery fish spawn together. This is being done to expose any differences that may exist in the capacity of wild and hatchery females to secure territory locations and spawn. The results of the fieldwork performed in 2000 indicated that such competition would occur when $\leq$ 8 m^2 is allotted per female. Consequently, 2001 and 2002 when both hatchery and wild females were allowed to spawn together in the observation stream the instantaneous female density equaled about 8 m^2 per female.

Modified fyke nets were placed at the end of each section of the observation stream to obtain a systematic sample of fry that could be used to perform the DNA pedigree analysis. This trapping effort also allowed us to measure the egg-to-fry survival rate in the channel. Altogether about 24,000 fry were produced and egg-to-fry survival was estimated to be slightly higher than 66 percent.

In conclusion, the observation stream provided an excellent quasi-natural environment where reproductive success could be objectively appraised. Observations on spawning spring chinook that would be logistically difficult if not impossible to conduct in the Yakima River can be performed in the stream. Because of this we have the infrastructure and techniques to assess whether differences exist between hatchery and wild origin adult spring chinook during their reproductive period.

All results presented in this report should be considered preliminary until they are published in the peer-reviewed literature.

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INTRODUCTION

Recent Endangered Species Act (ESA) listings of salmonids throughout the Western United States, including the Columbia Basin have required management agencies to develop plans to protect and recover these fishes. A variety of recovery strategies are being implemented, ranging from efforts that preserve and restore natural habitats to those that use captive-brood programs. The process of developing and engaging in salmonid recovery has fostered a re-evaluation of the role of salmon hatcheries. Prior to ESA listings, these facilities usually served as important sources of harvestable fish. In some circumstances hatcheries are now being used to preserve scarce genetic resources or to produce fish that can supplement adjacent natural populations.

Using hatcheries to supplement salmonid populations is not a new conservation strategy. In the early 1990's BPA supported an effort referred to as the Regional Assessment of Supplementation Project or RASP that was charged with defining supplementation and delineating its risks and benefits. RASP (1992) defined supplementation as the use of artificial propagation to increase natural production. In addition, to be successful, RASP stated that supplementation efforts would have to maintain the genetic integrity of the target population and create acceptable genetic and ecological impacts on non-targeted populations. Two inter-connected questions were generated by the RASP review. First, how should supplementation occur, and secondly how should its effects be monitored and evaluated? The Yakima Fisheries Project was designed to address both of these questions. The approach taken was to build a main hatchery with three satellite acclimation sites. Wild spring chinook native to the upper Yakima River would then be imported into the main hatchery and spawned. Their offspring would be raised for a period of time under different regimes and then distributed to the acclimation sites for final release.

In 1997 the main hatchery was built adjacent to the Yakima River near Cle Elum and the three acclimation sites, which are situated throughout the upper Yakima River basin, were established in 1997 and 1998. The number of raceways each of these sites possesses (18 for the main hatchery and 6 in each acclimation site) plus their rearing capacity was determined *a priori* by a power analysis. This analysis estimated how many hatchery-origin adult fish would need to return to the Yakima River to statistically evaluate the alternative supplementation strategies implemented at the hatchery. In addition, a detailed genetic risk assessment and overall monitoring and evaluation plan was developed for the project (Busack et al. 1997).

The genetic risk assessment contained three significant provisions. First, mating among the fish used as brood stock would be random with respect to their phenotypic traits; second, factorial crosses would be used when gametes were fertilized; and third, adult fish produced from the hatchery would not be used as broodstock but instead would be allowed to reproduce under natural conditions in the Yakima River. The intent of random mating was to maintain genetic diversity and to ensure proportional representation of the different life-history strategies embedded in the Yakima spring chinook population. Factorial mating was initiated to maximize the likelihood of each parental fish producing some offspring. Although gamete viability is generally high in salmonids, some individuals can be infertile; therefore if only single pair matings are used individuals crossed with nonviable partners will not produce any offspring. Not only does such an outcome profoundly affect the genetic fitness of the fish involved but it may also reduce the overall effective population size of the supplemented stock. The final tactic of not using known hatchery-origin adults as broodstock in succeeding years was proposed to reduce any inadvertent domestication effects that may manifest themselves because of the selection regimes hatchery-origin fish experience.

The tactic of recycling first generation hatchery fish back into natural production assumes that such fish will be reproductively competent. If they are not, then the strategy of cycling fish through an artificial environment may actually reduce the size of the population that has been targeted for supplementation. This argument was mathematically framed by Busack (personal communication) who proposed that a supplementation effort could be regarded as successful if the recruitment rate of wild adults brought into a hatchery (R_{WH}) times the recruitment rate of their offspring spawning in the wild (R_{HW}) was greater than the recruitment rate of wild fish (R_{WW}) that were not exposed to hatchery conditions or: (R_{WH}) x (R_{HW}) > (R_{WW}) x (R_{WW}). For clarification purposes, suppose that 100 adult salmon were brought into a hatchery and that they produced a total of 1000 adults. Those 1000 adults then spawned under natural conditions and each of these fish produced 5 adult offspring. In this case, (R_{WH}) equals 10 (1000 mature offspring/100 parents) and R_{HW} is 5 therefore (R_{WH}) x (R_{HW}) equals 10 x 5 or 50. Suppose further that the salmon that were not brought into the hatchery produced on average 7 adult offspring and that each of their offspring also produced another 7 adult fish. In this case (R_{WW}) x (R_{WW}) would equal 7 x 7 or 49. In this example, supplementation would be considered a success because the individuals brought into the hatchery created more F_2 fish than would have transpired if no hatchery intervention had taken place. This occurred even though adult fish produced from hatchery parents were less successful than wild spawners at producing adult offspring when they spawned under natural conditions.

Flagg et al. (2000) feel that supplementation programs can only be appraised after all hatchery introductions have ceased. Their paradigm relies on comparing salmonid abundance before and after hatchery intervention programs have taken place. In this situation, a successful supplementation program is one that has created a persistent increase in abundance after hatchery releases of fish are no longer being implemented. The implicit assumption in this approach is that supplementation efforts will only occur when the factors constraining a population have been addressed by management decisions. Closure of fisheries and habitat renovation would be examples of such decisions since both should provide a population with opportunities to maintain an increased level of abundance. Clearly if the factors that have historically constrained a population have not been ameliorated the population will revert to its original size and supplementation will not have occurred.

No matter how supplementation success is measured it depends on the capacity of hatchery-produced fish to reproduce under natural circumstances. Reproductive success is dependent upon a complex series of events. First, each individual has to allocate caloric resources into body mass, gonads, and retrievable energy stores that can be used for migration, and spawning activities. And second, fish must mature at appropriate times. Maturation timing is critical because it determines whether an individual will encounter potential mates and it is also directly linked to progeny survival. If offspring are incubating when conditions are unfavorable or enter their rearing habitats at unsuitable times their survival will be affected. Plainly, the environments fish live in and the historical circumstances their ancestors experienced shape the energy allocation strategies and maturation schedules that are prevalent in populations. Therefore traits associated with reproduction like fecundity, egg size, and allocation of energy for migration and other behavioral tasks represent compromises between competing selection pressures. If a female, for instance, allocates an inordinate amount of energy toward the production of eggs in an effort to increase progeny number she reduces the likelihood that she will have enough energy for migration, egg burial, and redd defense activities. Failure to perform these tasks will affect her ultimate reproductive success no matter how many eggs she may possess. Moreover, if energy allocation strategies are heritable, unacceptable strategies will be reduced or eliminated over time, as fish possessing them will produce fewer offspring than contemporaries that possess more suitable strategies.

Hatchery environments are distinctly different from natural settings in two important ways. Unlike natural environments, incubation and rearing conditions in hatcheries are designed to be relatively constant from one generation to the next. Such constant conditions produce stable selection regimes that may push traits in one direction. In addition, many of the tasks associated with reproduction are eliminated in hatcheries. For example, females no longer have to search for territories; dig multiple nests, construct complex redd mounds, or expend energy guarding recently deposited eggs. Consequently, energy that normally would have been allotted into these tasks is no longer needed and can be diverted into other areas. In this instance, a female that used an energy allocation strategy that increased egg number to increase progeny production may increase her fitness since the restrictions associated with using this strategy under natural conditions no longer exist in a hatchery environment. Theoretically then the combination of a relatively constant environment and one that eliminates the need to execute certain behaviors in order to be reproductively successful provides a strong impetus for cultured fish to diverge from the behavioral, physiological, and morphological strategies that they use in natural spawning situations.

Even though hatchery-origin and naturally produced salmonids experience divergent environments for a portion of their life-times a European view has been that hatchery-origin fish can reproduce successfully under natural conditions. Perhaps the origin of this perspective is the belief that traits closely allied to fitness should have little genetic variation. Subsequently even though the fish experience contrasting environments that may favor distinctly different life-history capabilities the genetic variation needed to fully adapt to a hatchery environment may simply not be extant in such populations. One manifestation of this assumption was a concern that Atlantic salmon escaping from sea ranches located in northern Europe would breed with wild conspecifics and cause severe out-breeding depression to occur in natural populations. A number of studies were performed that compared the traits and reproductive competence of farmed and wild Atlantic salmon and sea trout (*see* Fleming and Peterrson 2001). Comparable investigations were performed on North American salmonids. These studies indicated that morphological, physiological, and behavioral differences often exist between wild and hatchery-origin salmonids (Table 1.). In some instances, investigators also examined the consequences of the differences they observed on the breeding success of hatchery- and wild-origin fish that either spawned together or in separated areas (Table 2.).

The information summarized in Tables 1 and 2 were gathered on hatchery populations that had been under culture from one to five or more generations. Even though these observations were collected on a variety of species several persistent trends exist. First, the more generations a population experiences in a hatchery environment the greater the likelihood it will suffer from inadvertent domestication. Second, the greater the length of time a fish is reared the more likely it will differ from wild progenitors. Consequently, species like Atlantic salmon, steelhead, brown trout, coho, and spring chinook that are traditionally reared for twelve to twenty-four months are more likely to be impacted by hatchery conditions than are species like fall chinook, chum, sockeye, and pink salmon that are often reared for three months or less. Third, the differences shown in Table 1 are induced by both genetic and environmental causes (Fleming and Petersson 2001). Fourth, the changes induced by artificial culture deleteriously affect the breeding success of hatchery-origin fish when they reproduce under natural conditions. And finally, the impact of hatchery life on naturally spawning males and females is not equivalent; males typically experience a greater deficit in breeding success than females.

Some of the studies shown in Tables 1 and 2 compare native salmonids with farmed or captive-brood counterparts. Farmed fish have been selectively bred to possess traits that make them amenable to intensive culture and eventual human consumption. Although cultured for entirely different purposes, captive brood fish also spend their entire life times in culture before being spawned or liberated into ancestral spawning areas. Consequently differences between their traits and those possessed by wild fish are probably not representative of the disparities that exist between more typically reared hatchery fish and wild salmonids. Jonsson and Fleming 1993 and Fleming et al. 1997, however, did compare hatchery Atlantic salmon with wild cohorts and found that exposure to hatchery conditions for a single generation reduced the breeding success of the cultured fish (Table 2.). In addition, studies performed in the Columbia Basin on Tucannon spring chinook showed that size-at-age, fecundity-at-age, and mean-age-of maturity were all reduced in F_1 hatchery females (Bumgarner et al. 1994). Further work on this population (Gallinat et al. 2001) illustrated that these differences were largely induced by the environmental conditions that the hatchery-reared fish experienced.

Table 1. Results of morphological, physiological, and behavioral comparisons made between adult wild- and hatchery-origin salmonids.

Type Of Comparison	Citation	Species	Observations
Morphology Of Hatchery Fish Compared to Wild Cohorts	Fleming and Gross 1992	Coho	1) Hatchery females had smaller kypes, reduced body depths and lengths
	Berejikian et al. 1997	Coho (Captive Brood)	1) Hatchery males were less fusiform than wild cohorts
	Hard et al. 2000	Coho (Captive Brood)	1) Hatchery male and female fish had reduced sexual dimorphism, smaller heads, less hooked snouts, increased trunk depth, larger caudal peduncles, shorter dorsal fins, larger hind bodies and a reduction in streamlining
	Petersson et al. 1996	Atlantic Salmon	1) Hatchery females were less fusiform than wild fish
	Webb et al. 1991	Atlantic Salmon (Sea Pen fish)	1) Sea Pen Atlantics were found to be less fusiform than wild fish
	Petersson and Jarvi 1993	Brown Trout	1) Wild males were longer and heavier than sea-ranched fish. When adjustments for size were made no differences were found in kype, jaw, nose, and adipose fin size 2) Wild and sea-ranched females did not differ in size, wild females did on average have longer noses than sea-ranched females
	Fleming et al. 2000	Atlantic Salmon (Farmed fish)	1) Farmed males were significantly larger than wild males

Table 1. Results of morphological, physiological, and behavioral comparisons made between adult wild- and hatchery-origin salmonids continued. . .

Type Of Comparison	Citation	Species	Observations
Physiology of Hatchery Fish Compared to Wild Cohorts	Fleming and Gross 1992	Coho	1) Hatchery females had greater egg masses, increased reproductive effort, larger eggs, and smaller fecundities 2) Hatchery males had larger testes
	Fleming and Gross 1989	Coho	1) Total egg mass was found to be greater in coho salmon females originating from a number of hatchery populations
	Fleming and Gross 1990	Coho	1) Egg size was found to be larger in hatchery coho
	Berejikian et al 1997	Coho (Captive Brood)	1) Hatchery male and female adults had less carotenoids and possessed muted nuptial color patterns when compared to wild fish
	Fleming et al. 1996	Atlantic Salmon	1) Hatchery fish had lower cardiac/somatic index values (were in poorer physical condition) than wild-origin fish.
	Petersson and Jarvi 1993	Brown Trout	1) Ovulation in sea ranched females occurred one week later than in wild females. However, no differences were found in egg mass weights or egg size.
	Fleming et al. 2000	Atlantic Salmon	1) Testes weights were the same between wild and farmed fish, egg sizes in farmed females were significantly smaller than those in wild females
	Petersson et al. 1996	Atlantic Salmon & Brown Trout	1) Egg biomass in cultured Atlantic salmon was comparable to wild fish. Wild and hatchery-origin brown trout also had comparable egg biomasses. Egg size however, was greater in hatchery females in both species

Table 1. Results of morphological, physiological, and behavioral comparisons made between adult wild- and hatchery-origin salmonids continued. . .

Type Of Comparison	Citation	Species	Observations
Reproductive Behavior of Hatchery Fish Compared with Wild Cohorts	Fleming and Gross 1992 & 1993	Coho	1) When hatchery- and wild-origin females competed for spawning sites, hatchery-females were delayed, and spawned in less desirable areas, no evident differences existed, however in aggressive or submissive behavior. In addition, both types of females spent the same amount of time spawning, digging and probing frequencies, nest depths, the likelihood of being courted were also similar. Hatchery females retained more eggs and were less successful at guarding nest sites. 2) Hatchery males were found to be less aggressive and more submissive than wild males. Hatchery males also exhibited less courting behavior, were alpha males less frequently, and spawned fewer times than wild-origin males. Both types of males had similar lifetimes.
	Berejikian et al. 1997	Coho (Captive Brood)	1) Wild females established nests earlier, and produced more nests than captive brood females. 2) Wild males dominated captive-brood males. Moreover, captive-brood males were attacked more often by females than wild males.
	Berejikian et al. 2001	Coho (Captive Brood)	1) Wild males dominated captive-brood males in size-matched contests
	Lura et al. 1993	Atlantic Salmon	1) Farmed Atlantic salmon had more nests per redd and placed fewer eggs in nests than wild females. Farmed females were less accurate in egg deposition and covering.
	Fleming et al. 1996	Atlantic Salmon	1) Farmed Atlantic salmon females displayed less breeding behavior, constructed fewer nests, suffered more nest destruction and had fewer surviving offspring than wild cohorts 2) Farmed males were less aggressive, courted less, spawned fewer times, and exhibited maladaptive breeding behavior.
	Fleming et al. 2000	Atlantic Salmon	1) Farmed and native fish had similar migration patterns and spawning locations, although farmed females spawned before wild females. Farmed females also dug fewer nests. 2) Farmed males were less aggressive, courted less, spawned fewer times, and exhibited maladaptive behavior.

Table 1. Results of morphological, physiological, and behavioral comparisons made between adult wild- and hatchery-origin salmonids continued. . .

Type Of Comparison	Citation	Species	Observations
Reproductive Behavior of Hatchery Fish Compared with Wild Cohorts	Chebanov and Riddell 1998	Chinook	1) In most of their trials, wild males dominated hatchery-origin males, hatchery males were often the victims of wild-origin male aggression 2) Hatchery-origin females were more active in courtship and were more aggressive than wild females.
	Petersson and Jarvi 1997	Brown Trout	1) Hatchery-males courted females less than their wild counterparts and participated in fewer spawnings. 2) Hatchery-origin females performed fewer nest building activities, were not as aggressive, and defended themselves and nest sites less frequently than wild females
	Webb et al. 1991	Atlantic Salmon	1) Wild males and females tended to spawn in higher portions of the studied watershed, also farmed males and females spawned later than wild fish

Table 2. Results of comparisons made between the reproductive success of hatchery- and wild-origin salmonids.

Species	Generations In Culture	Sex	Relative Efficiency (Hatchery vs. Wild)	Citation
Coho	4 to 5	Male Female	47 to 62% 82 to 88%	Fleming and Gross 1993
Atlantic Salmon	1	Male Female	65% 82%	Jonsson and Fleming 1993
Atlantic Salmon	1	Male Female	51% No difference	Fleming et al. 1997
Atlantic Salmon	5	Male Female	1 to 3% 20 to 40%	Fleming et al. 1996
Atlantic Salmon	5	Male Female	24% 32%	Fleming et al. 2000

The ultimate goal of a supplementation program is to seamlessly integrate hatchery-produced fish into a depressed population with the intent of creating an enduring increase in its abundance. In spite of the fact that hatchery fish are often used in supplementation programs very little evaluation and monitoring work on this management strategy has been done (Fleming and Petersson 2001). As Tables 1 and 2 illustrate, however, hatchery-origin fish appear to be reproductively less competent than wild fish when both spawn under natural conditions. For this reason, Fleming and Petersson (2001) feel that supplementation programs using hatchery fish should be of short duration. They also state that the performance of hatchery adults and their offspring in natural environments is largely unknown. The Yakima Fisheries Supplementation Program has a number of unique attributes that make it an ideal project to objectively assess the performance of hatchery fish and their offspring when both are forced to adapt to natural conditions.

Unlike many situations, the upper Yakima River spring chinook population has experienced few or no releases of hatchery-origin fish and therefore it can act as a legitimate representative of wild fish. Because of how supplementation is taking place the project will provide a conservative test for differences between hatchery- and wild-origin fish originating from the same population. Two factors make it a conservative test. First, the adult collection, rearing, and release protocols established for Cle Elum Hatchery were designed to limit inadvertent domestication as much as possible. As a result, the hatchery regime provides long-reared salmonids with the best chance to produce adults that do not possess deficits in their morphology, physiology, or behavior. Second, the mating and rearing procedures followed at the hatchery are consistently applied for at least five continuous years before any changes are instituted. The latter approach was implemented in an attempt to lessen year-to-year variation in the hatchery treatment. Consequently, if differences between hatchery- and wild-origin fish are found it means that hatchery programs with less stringent safeguards are likely to have larger effects on their fish than those reared under the Cle Elum protocols. Finally, since its inception in 1997 a variety of biological traits have been measured on the wild fish used as brood stock and their offspring. Such data are not often collected and they will be used as a baseline to track changes in selected traits.

The most cogent way to assess differences between hatchery- and wild salmonids living in natural environments is to compare their fitness values. Fitness is measured by assessing how successfully individuals can move their genes through time. For completeness such an evaluation would also include how well their genetic relatives are able to perpetuate their genes across generational time as well. How successfully a fish is able to transition from one life history stanza to the next obviously affects its potential fitness. For instance, was it able to deposit its gametes at the proper time and place, did any of its subsequent offspring survive their incubation period, emerge, disperse, grow and eventually go through smoltification or mature precociously? Those that smolted must migrate, adapt to seawater, complete an oceanic feeding migration, readjust to freshwater and migrate back to their natal spawning grounds. Offspring that mature without a period of seawater feeding avoid some difficulties but face others and like their anadromous kin must produce zygotes by participating in spawning events. If an individual, its offspring or relatives fail to accomplish any of these linked tasks their fitness will plainly be reduced.

Comparing the fitness of two types of salmonids is quite challenging because of all the factors that can influence survival and breeding success. We believe however, that insights into potential inequalities can be gained by comparing the performance of each type of fish at different times in their life cycle. The principle objective of this document is to describe the approach taken to evaluate the breeding success (the ability to deposit gametes) and capacity to produce fry under natural conditions of hatchery- and wild-origin Yakima River spring chinook. To make such comparisons an observation stream was built at the Cle Elum Hatchery in 2000. In September of 2000 wild spring chinook were placed into the stream to: 1) ascertain whether chinook would spawn in this quasi-natural setting, 2) determine how many females should be placed into the stream to induce low levels of competition for space, 3) see if specific breeding behaviors could be linked to successful gamete deposition and production of offspring, 4) discover if reproductive success was linked in anyway to the possession of certain phenotypic traits, 5) find out whether eggs deposited in the channel could survive to the fry stage, and 6) delineate how newly emerged fry should be captured and sampled for a subsequent pedigree analyses based on micro-satellite DNA.

Most of the spring chinook adults returning to the upper Yakima are four-years old. The first four-year-old fish produced by the hatchery returned to the Yakima in 2001. Some of these fish plus wild-origin chinook adults were placed into the observation stream in September of 2001. In 2002, both four- and five-year-old hatchery fish were available and a number of these fish plus wild spring chinook were again allowed to spawn naturally in the observation stream. The procedures developed and refined during the 2000-01 spawning and fry emergence seasons were utilized to directly compare the breeding success of the hatchery and wild fish placed into the observation stream in 2001 and 2002. Samples of the fry from the adults that spawned in the channel in 2001 are currently undergoing DNA analyses while juveniles generated by the 2002 adults are still incubating in the channel. Pedigree analyses, however, have recently been completed on fry produced by the adult fish placed into the observation stream in 2000. In this report we describe the channel, its environmental conditions, the procedures used to introduce adult fish into the structure, how their behavior was monitored, the types of post mortem data collected on fish that spawned in the observation stream, how fry were counted and sampled, the procedures used to assess female intra-sexual competition for space, and the results of the pedigree analysis. Future reports will describe results of the reproductive success comparisons made between hatchery- and wild-spring chinook placed into the channel in 2001 and 2002.

METHODS

Observation Stream

As previously mentioned, during the summer of 2000 an observation stream or small spawning channel was built on the grounds of the Cle Elum Hatchery to evaluate the reproductive success of hatchery- and wild-origin Yakima spring chinook. The stream is 127 m (416 feet) long by 7.9 m wide (26 feet) and is stretched out in the shape of a "U" (Fig.1.). The area where the stream was built did not originally possess enough gradient to create desired water velocities. Consequently, earthen fill was imported and used to raise the first section of the stream 2.1 meters higher than its tail end. A 9 m wide (29-

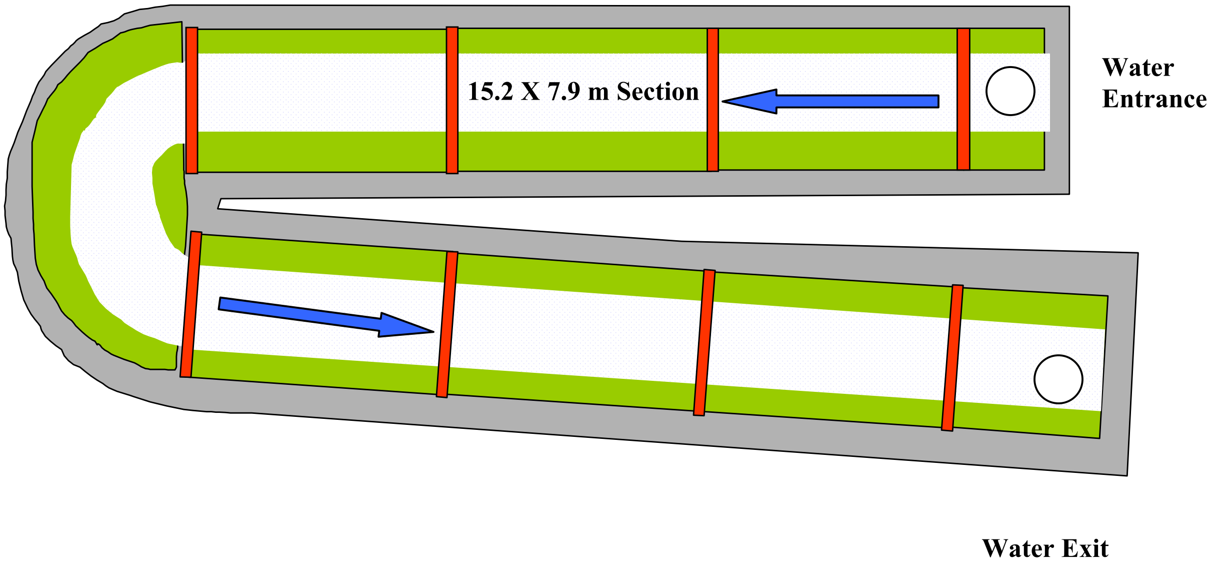

Fig. 1. Schematic diagram of the 127 m long by 8 m wide observation stream built at the Cle Elum Hatchery to evaluate the reproductive success of hatchery- and wild-origin spring chinook. The bars separating each section represent the concrete cross weirs.

constructed in the imported gravel at the upper end and in the native sub-grade in the lower 45.7 m (150 feet) of the stream. The trough was lined with black geotextile, a semi-permeable felt-like material that was used to reduce water loss from the stream. The walls of the stream had 2:1 slopes and were armored with bull rock that was 10 to 20 cm in diameter. The channel itself was filled with up to a 90-cm thick layer of double washed river rock that is predominately 0.14 to 4.4 cm in diameter (Table 3).

Table 3. The size distribution of the gravels placed into the observation stream.

<table>
<tr><th colspan="6">Gravel Mixture Requested</th></tr>
<tr><th>Screen Size (Metric mm)</th><th>Mid Point Of Gravel Size (mm)</th><th>Percent Passing The Screen</th><th>Percent Retained By The Screen</th><th>Geometric Mean Of The Gravel Used (mm)</th><th>Fredle Index Of The Gravel Mixture</th></tr>
<tr><td>100</td><td>100</td><td>98%</td><td>2%</td><td></td><td></td></tr>
<tr><td>63</td><td>81.5</td><td>85%</td><td>13%</td><td></td><td></td></tr>
<tr><td>25</td><td>44</td><td>50%</td><td>35%</td><td></td><td></td></tr>
<tr><td>19</td><td>22</td><td>15%</td><td>35%</td><td></td><td></td></tr>
<tr><td>9.5</td><td>14.25</td><td>5%</td><td>10%</td><td></td><td></td></tr>
<tr><td>4.75</td><td>7.13</td><td>0%</td><td>5%</td><td></td><td></td></tr>
<tr><td>2</td><td>3.38</td><td>0%</td><td>0%</td><td></td><td></td></tr>
<tr><td>Pan</td><td>1</td><td>0%</td><td>0%</td><td>31.01</td><td>21.93</td></tr>
<tr><th colspan="6">Gravel Mixture Obtained</th></tr>
<tr><td>100</td><td>100</td><td>100%</td><td>0%</td><td></td><td></td></tr>
<tr><td>63</td><td>81.5</td><td>91.8%</td><td>8.16%</td><td></td><td></td></tr>
<tr><td>25</td><td>44</td><td>60.7%</td><td>31.1%</td><td></td><td></td></tr>
<tr><td>19</td><td>22</td><td>39.3%</td><td>21.4%</td><td></td><td></td></tr>
<tr><td>9.5</td><td>14.25</td><td>22.2%</td><td>17.1%</td><td></td><td></td></tr>
<tr><td>4.75</td><td>7.13</td><td>7.8%</td><td>14.4%</td><td></td><td></td></tr>
<tr><td>2</td><td>3.38</td><td>0%</td><td>7.9%</td><td></td><td></td></tr>
<tr><td>Pan</td><td>1</td><td>0%</td><td>0%</td><td>20.67</td><td>11.77</td></tr>
</table>

Concrete cross weirs subdivide the stream into seven sections; six are 15.2 m (50 feet) long by 7.9 m (26 feet) wide while the elbow section that links the two arms of the stream is 21.3 m (70 feet) long by 7.9 m (26 feet) wide. Each section is level but a 30 cm drop occurs between a cross weir and the section that lies directly downstream of it. A longitudinal section of the stream would thus resemble a staircase, with 15 m long level steps separated from one another by 30 cm high risers. The concrete cross weirs are 2.1 m in height (6 feet 10 inches), 30 cm thick (1 foot) and 7.9 m (26 feet) wide. Two 1.8 m (6 foot) wide by .9 m (3 foot) high openings exist in each weir and they are separated by a solid .61 m (2 foot) center piece. The bottom and two sides of the openings have 15 cm (6 inch) deep by 8 cm (3.25 inch) wide slots so that dam boards, pickets, or fry traps can be easily installed. In addition, each cross weir has a 60 cm wide (2 feet) wooden plank walkway that spans its entire width. The walkway is positioned on the downstream side of the cross weir and is used when pickets or fry traps are installed or for other routine tasks. In addition, each cross weir has a safety rail made by spacing five 1.1 m (3.5 feet) vertical stanchions across its width. A single chain feeds through the stanchions to complete the railing that is located on the upstream side of each cross weir.

The water supply for the observation stream originates from a 1.2 m diameter effluent pipe that collects water leaving the hatchery's 18 raceways. Four, 25 HP electric pumps pull water from the effluent pipe and deliver it to a 91 cm diameter outlet pipe that provides water to the head end of the stream (see Fig. 1.). The quantity of water entering the stream can be regulated by operating one or more of the pumps and by using a gate valve located in the channel's water supply line. The water velocity (30 to 90 cm/s) and depth (> 30 cm) parameters established for the channel follow those used by naturally spawning spring chinook (Bjornn and Reiser 1991). Water velocity and stream depth measurements are systematically made throughout the stream at two times, once prior to fish introduction and again during the incubation period. A 6 m (20-foot) long painter's plank is stretched across the stream to reach measurement points when eggs and fry are incubating to protect them from being destroyed by crushing or mechanical agitation. The velocity and depth data are analyzed using the six-tenths-depth method (Buchanan and Somers 1969) to calculate the volume of water entering the stream. Furthermore, a water height gauge was placed on the upstream side of the uppermost cross weir to provide a rapid way to monitor changes in water flow. Water depth is maintained by placing dam boards in each cross weir and water temperatures are recorded once every two hours by using StowAway Tidbit Temperature Loggers. Once water has passed through the stream it enters a 1.2 m diameter pipe that transports it to a natural oxbow and wetland area (see Fig. 1.).

The stream receives water from mid-September through May and completely dries up when water is not pumped into it. Gravel samples are taken twice each year, immediately before the stream is activated in the fall and shortly after it is shut down in the spring. Three gravel samples are removed from each section by using a McNeil gravel sampler (McNeil and Ahnell 1964). The gravel samples are then thoroughly dried and passed through a series of nine (125, 100, 63, 25, 19, 9.5, 4.75, 2, .075 mm and a final collection pan) graduated sieves. The weight and percentage of the sample captured by each screen is determined and used to produce a gravimetric estimate of the general gravel composition found in each section of the stream. Because the water used in the channel comes from the hatchery raceways it contains organic sediments and sand and therefore a yearly gravel cleaning program has been instituted to ensure that the spawning gravel does not contain unacceptably high concentrations of sand or smaller materials. A Bobcat tractor equipped with rubber caterpillar tracks and a backhoe is driven into the stream. Water is pumped into the structure and the backhoe is used to dig up spawning gravel that is washed by pressurized water originating from a gas-powered pump. The cleaning procedure starts at the head end of the structure and moves downstream. Gravel is cleaned and agitated until no visible silt or water discoloration occurs. The gravel samples mentioned above are taken before and after cleaning and thus represent the type of substrate available to the adults at spawning and what was experienced by their offspring at the end of the incubation period.

Selecting and Placing Adult Spring Chinook Into The Observation Stream

Spring chinook returning to the upper Yakima River are randomly selected at the Roza Adult Monitoring Facility and transported to the Cle Elum Hatchery where they are held in one of two (30.5 m long by 4.6 m wide by 3 m deep) adult holding ponds. Beginning in early September the fish are examined once a week to determine which may have reached maturity. Mature fish destined for the channel are captured by dip net and anesthetized in a solution containing one part of MS222 to 19,000 parts of water (Bell 1964). Once docile, each fish is weighed to the nearest gram on an electronic balance, has its fork length taken in mm, and is tagged with numbered, 3.8 mm in diameter Petersen disks. Yellow and white tags with black numbers ranging from 01 to 99 are used and fish of the same sex receive tags having the same color. Care is taken to use numbers that are not easily confused with one another, for example if a female receives tag 01, then tag number 10 is not used on another female. DNA samples on each fish are obtained by removing a piece of skin from the posterior edge of the dorsal fin. These samples are placed into labeled vials containing 100% ethanol and are transferred to WDFW's Genetic Laboratory for later DNA extraction and analysis. After the fish were processed one or two individuals were placed into a 124 *L* capacity insulated cooler and transported to the observation stream where they were liberated. After being anesthetized it took approximately 3 minutes to tag, sample, and liberate a fish into the observation stream. All the fish placed into a section of the stream were tagged and liberated on the same day; this process usually took less than two hours to complete.

Behavioral Observations

Observation Walls and Grid System

A 2.1 m (7-foot) tall wall was built around the outside and inside banks of the observation stream. It was made by using 10 cm x 10 cm x 3 m tall (4 inch x 4 inch by 10 foot) fence posts that had 5 cm by 10 cm (2 by 4 inch) top and bottom railings. Camouflage netting was attached to the posts and railings to create a continuous wall of netting. This material is porous enough to allow wind to pass through it but opaque enough to obscure any movement occurring behind it. Openings in the netting were cut at eye level along every 2 meters of its length to allow observers to view fish placed into the stream. Each section also had a grid system made of 0.6 cm (¼ inch) nylon cord stretched approximately 30 cm over the surface of the water. Each rectangle in the grid measures 1.5 m wide by 3 m long and was provided with a unique alphanumeric designation (Fig. 2) in addition, each of the seven sections of the stream were also provided with unique designations. The upper three sections are called sections 1-1 (the uppermost section), 1-2, and 1-3, the bend in the stream connecting its two arms is called the "elbow" while the last three sections are referred to as sections 2-1, 2-2, and 2-3 (the last section).

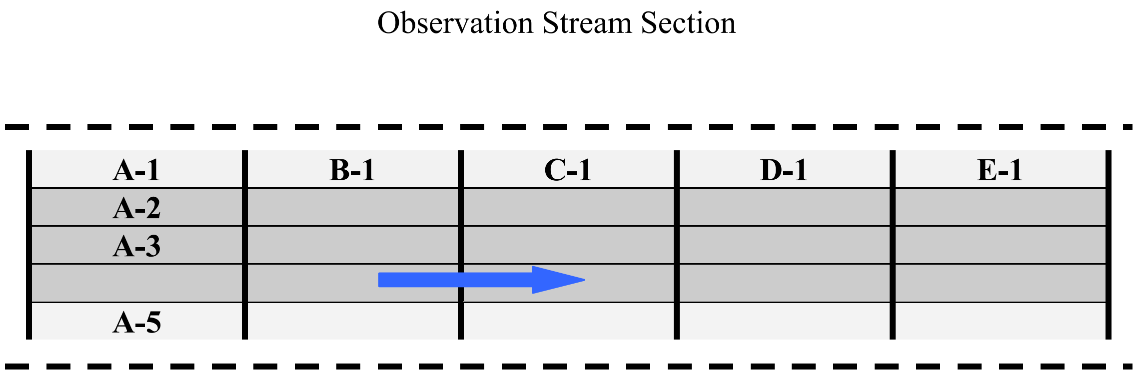

Fig. 2. A diagram showing the alphanumeric system used to identify rectangles in the grid system placed over one section of the observational stream. This nomenclature was consistently applied to all sections in the stream. Those portions of the grid shown in dark gray represent areas of the streambed that were often covered with water while the lighter gray cells show bank areas that were typically not inundated with water. The arrow indicates current direction and the dashed lines show the location of the observation walls.

Scan, Focused, And Longevity Observations

Scan and focused behavioral observations are made on fish placed into the observation stream. Scan observations are made by recording the activities of a single fish into a tape recorder for four continuous minutes. At the beginning of each scan, the date, time sex, and tag number of the observed fish is noted. The location of each individual is also recorded by indicating which cells in the grid system it occupies or passes through. In addition the basic color pattern of each fish is recorded. Previous observations on spawning chum salmon showed that nuptial color patterns can quickly change (within seconds) and are often directly related to the social status of an individual (Schroder 1981). Consequently, a brief description of the color pattern exhibited by a fish while it was being observed was made to determine if similar relationships between color patterns and behavior could be made in spring chinook. The types of behavioral data extracted from the scan observations were sex-specific. For example, the following information on females was collected each time they were observed: 1) their social status, i.e. whether they were territorial or non-territorial and if they were territorial were they actively constructing nests and spawning or guarding a completed redd, 2) the occurrence of any nest construction or nest testing activities like probing and digging, 3) the tag numbers of any alpha (dominate male) and satellite males (sub-dominate) associated with the female, and, 4) the agonistic interactions the fish experienced, who they chased, bit, and rammed and who attacked them. Information on males included: 1) their social status, that is whether they were wandering, alpha (primary courting male) or satellite males, 2) the occurrence of any courting behavior e.g. caudal peduncle crosses and quivering, 3) the tag numbers of any females that were courted or that a male was a satellite to, and 4) the agonistic interactions the male experienced, frequency and target of lateral displays, who was chased, bit, rammed, and who attacked the observed male. Scan observations were made continuously during day light hours for as long as the females in a section were spawning, a period that usually lasted 48 to 72 hours.

Focused observations were produced in a similar manner. In this instance, however, the activities of a spawning pair and the fish they interacted with were continuously dictated into a tape recorder. Typically such observations included one or more hours of pre-spawning activity and thirty minutes or more of post-spawning behavior. These records were transcribed into continuous ethograms and used to create temporal frequencies of obvious male and female spawning and agonistic behaviors that occurred before and after spawning. The length of time each fish lived after it was released into the observation stream was also determined by inspecting the stream at least three times each day for mortalities. The time of death for each fish was thus determined to at least the nearest eight hours.

Assessing Female Intra-sexual Competition For Spawning Locations

In the fall of 2000, two different instantaneous densities of gravid females were released into the observation stream. In one case, 8 females were simultaneously released into section 1-1 while 4 females were liberated into section 1-2. Both of these sections were 4.5 m wide by 15.2 m long. The size, location, and water velocity profiles associated with every female's redd was determined. This information was linked to when a female established a redd to see if the physical traits associated with a spawning location were affected by when a female established a territory and by the number of other females in a section that were competing for redd sites. Two other measurements, egg retention at death, and the degree of redd superimposition that occurred in a section were also used to assess female competition. These attributes were chosen because previous work done on other salmonids showed that when competition for space increases egg retention can be high in females that delay in finding a territory. Moreover, redd superimposition also increases as female competition rises (Schroder 1973).

Post Mortem Observations

After a fish died it was weighed to the nearest gram and its fork length was determined in mm. The number of eggs a female retained was ascertained by opening her coelomic cavity and counting any eggs that had not been spawned. Any eggs firmly attached to the ovarian membrane were not included in these counts. Males were also dissected and their testes were carefully extracted and weighed to the nearest hundredth of a gram.

Estimating the Potential and Actual Egg Deposition Values of Females Placed Into the Observation Stream. The Potential Egg Deposition (PED) or fecundity of each female was estimated by using formulas that regressed body weight and egg weight on fecundity. The formulas were produced by using data collected on the females used as broodstock at the Cle Elum Hatchery. Separate formulas were generated for four and five year old fish. Actual Egg Deposition (AED) or an estimate of the number of eggs a female buried in the stream was determined by subtracting any eggs she retained at death from her fecundity estimate. In a few instances, some of the females shed a small number of eggs during the tagging process. When this occurred, the eggs were counted and also subtracted from a female's PED value. The eggs lost at tagging were also placed in labeled vials containing water, refrigerated for 24 hours, and then individually weighed to the nearest mg. These egg weights along with the body weight of a female were used to estimate individual PED values.

Estimating The Spawning Participation Of Males Placed Into The Observation Stream. Two independent measures of male participation were made. First, Bishop (1971) observed that the more times a male grayling spawned the redder and less full his testes became. Consequently, when a male was dissected an immediate assessment of the color and fullness his testes was performed. Four ranked categories were created, full and white (apparently unspawned), white with some pink coloration and but full appearing (light spawner), mostly pink and partially depleted (moderate spawner), and pink to red and at least 50% depleted (heavy spawner). Every male was inspected and had his testes placed into one of these categories. Secondly we estimated the percentage of a male's testes that had been depleted during his spawning lifetime. This was done by subtracting the weight of a male's testes at death from a testes weight he was predicted to have at maturation. The predicted unspawned testes weights were determined by using a regression formula that examined the relationship between male body weight and testes weight at maturity. Fig 3. depicts this relationship which was produced by obtaining

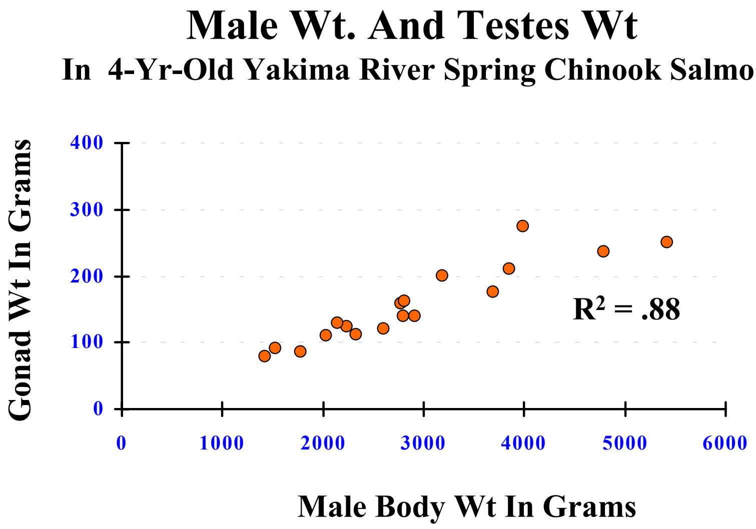

Fig. 3. The relationship between male body weight and testes weight in unspawned 4-year-old spring chinook returning to the upper Yakima River.

body and testes weights from unspawned spring chinook native to the Upper Yakima

River. Earlier work by Schroder (1973) illustrated that gonad depletion in male salmon was strongly correlated to the number of times a male expressed milt. Therefore a measure of gonad depletion may provide an estimate of how often a male may have participated in spawning events.

Estimating Egg-to-Fry Survival Rates

Modified fyke nets were used to capture all the fry that emerged and migrated from the observation stream. The nets were attached to wooden frames that were installed in the cross weirs located at the downstream end of sections 1-1 and 1-2. The nets were 3.7 m long, triangular in shape, made with .3 cm (1/8 inch) nylon mesh netting that had been treated with green guard, a plastic preservative. Each was equipped with a 60 cm long zipper located on the top panel that was used to remove debris. The mouth of every net was 1.8 m (6 feet) wide by 38 cm (15 inches) high while the tail end was 20 cm (8 inches) wide by 10 cm (4 inches) deep. A tapered Herculite (tough plastic material) collar was sewn onto the end of the net and a 10 cm diameter by 20 cm long ABS pipe with male threads on its downstream end was inserted into the collar. This pipe was firmly attached to the net by using a stainless steel hose clamp that was placed around the collar and tightened. A live-box was attached to the net by inserting the male end of the ABS pipe into a 10 cm hole located in the middle of the upstream side of the live box. The live boxes were attached to the ABS pipe by screwing a 10 cm female ABS union onto the pipe. The live boxes were 30 cm deep x 55 cm wide by 69 cm long and made with marine grade plywood. A Styrofoam log 69 cm long by 11 cm wide by 15 cm deep was attached to each side of the live box to keep it afloat. A 34 cm by 22 cm opening was re cut in the end of each live box and screened with .3 cm material. The interior of each box was painted white so that captured fry could be readily seen. Each box was also equipped with a hinged lid that could be locked.

The nets were installed in mid January, more than a month before fry were expected to emerge from the channel sections. Each live box was inspected one or more times per day and the fyke nets were scrubbed clean when needed. Planter's planks (6 m long by .6 m wide) were placed over the channel and just downstream of the floating live boxes so they could be inspected without having to walk in the observation stream. Captured fry were dip netted out of the live boxes and placed into 19 L buckets that were labeled so that the section the fry originated from could be identified. The fry in each bucket were counted by hand using a fine mesh strainer and tally whacker. Once all the fish collected from a section were counted a sub-sample was taken and preserved in 100% ethanol for later micro-satellite DNA analyses. The number of fish sampled each day per section was equal to or slightly higher than 10% and was determined by using the following procedure: multiply the total number of fry collected by 0.1 and collect that number of fry. If the product had a decimal point the value was always rounded up to the nearest whole number. For example, suppose that 220 fry were collected (220 x .1 = 22) then 22 fish would be collected, however, if 221 fry were captured 221 x .1 = 22.1) the sample size would be 23. The desired goal was to systematically and proportionately collect a total of 1000 fry from each section over the entire emergence period. At the end of the fry trapping season the total number of sampled fry was determined. If that total was greater than 1000 then an equal percentage of fry was randomly removed from each sample to produce an overall sample of 1000 fish. After fry emergence was completed, block seines and electro-fishing gear were used to capture any fish still remaining in the sections. These fish were counted and sub-sampled in the same manner as the daily catches were.

Determining The Number Of Offspring Produced By Adult Fish Placed Into The Observation Stream

Behavioral observations and post-mortem inspections of egg retention or gonad depletion may be used to estimate the breeding participation of individuals. These appraisals however, usually have uncertainties associated with them. Therefore it is often difficult to link these types of observations with precise estimates of the number of offspring an individual may have actually produced. A much more powerful approach is to use pedigree analyses based on genetic variation in micro-satellite DNA to assign the parental origin of sampled offspring. The fry samples collected from the observation stream were sent to WDFW's Genetic Laboratory and a pedigree analysis was performed (*see* Young and Shaklee (2002). These data were used to estimate two parameters in females. First, what percentage of their total eggs (PED) were converted to newly emerged fry. And second, what percentage of their deposited eggs (AED) survived to the fry stage. In addition, the total number of fry produced by each female was estimated by simple expansion. This was done by assuming that the 1000 fry sampled represented a true proportional mixture of the fry produced from the females spawning in a section. Therefore if 20% of the fry in the 1000 fish sample originated from a particular female it was assumed that 20% of the total number of fry produced from the section were her offspring. The total number of offspring produced by each male was determined in the same manner, i.e. the proportion of fry produced by a male in the 1000 fry sample was multiplied by the total number of fish sampled from his section.

RESULTS

Environmental Conditions In The Observation Stream

Water was first pumped into the observation stream in August of 2000. During this trial, hyporheic water was observed oozing from the banks that surrounded the upper 45 meters of the stream. To constrain this flow, a 60 cm wide by 1.5 m deep trench was dug around the upper part of the structure, lined with geotextile, and partially filled with fine clay. After the repair was completed, seepage rates were significantly reduced and the observation stream was put into operation in early September 2000.

Flow Rates and Water Depths In The Observation Stream

Bjornn and Reiser (1991) report that spawning spring chinook require flow rates that range from 30 to 91 cm/s (0.98 to 2.98 fps) and water depths that are $\geq$ 24 cm ($\geq$ 9.5 inches). Conditions that fell within those ranges were achieved in the observation stream by using two of the 25 HP pumps and leaving the gate valve situated in the water supply line completely open. Appropriate water depths were obtained by installing 29 cm wide dam boards in each cross weir. Under this pumping scenario the observation stream received approximately 0.46 cubic meters/s (16 cfs) of flow. Water velocity measurements made in the steam showed that a wide range of flow conditions existed in each section and that velocities were strongly affected by upstream cross weirs. Those portions of the stream that were directly below the open slots in a weir received the highest flows while the region that lay behind the 60 cm wide center piece of a cross weir experienced very low flows. For example in section 1-1, flows 3 meters below the left and right (looking upstream) openings in the cross weir averaged 55 and 76 cm/s (1.8 to 2.5 fps). Back eddies and still water areas lay adjacent to each of these parallel "thalwegs" and point estimates of velocities made in such regions showed that flow rates ranged from virtually zero to 9 cm or more per second. As water moved down a stream section, currents intermingled and velocities became slower. For instance, the velocity profile for a series of stations that were located 30 cm from the right hand bank and taken every 3 m downstream equaled 76 (2.5 ft), 61 (2 ft), 49 (1.6 ft), and 43 cm/sec (1.4 fps). The trend of decreasing flows in each section and the occurrence of quite water zones provided the fish with a heterogeneous spawning environment that covered the range of water velocities preferred by this species. Prior to fish introduction, water depths were fairly uniform and ranged from 33 to 43 cm (1.1 to 1.4 feet).

Water Temperatures

Tidbit temperature loggers recorded both in-gravel and in-water temperatures once every hour from fish introduction in mid-September through early May when fry emergence was completed. In-water and in-gravel temperatures were virtually identical (Fig.4.) and

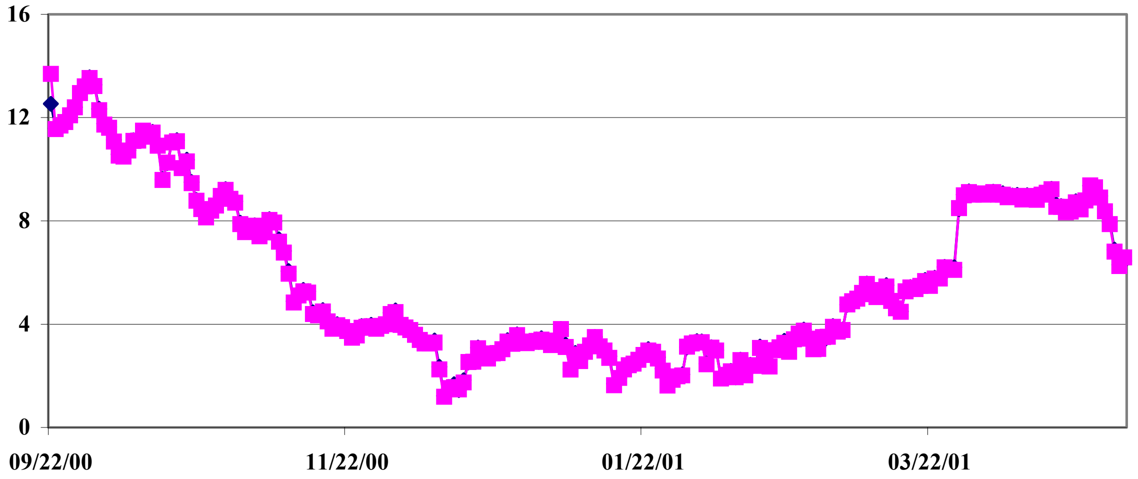

Fig. 4. Mean daily surface and in-gravel water temperatures in the observation stream during the 2000-01 spawning and incubation periods.

followed seasonal trends. For example, over the 222-day incubation period the average in-gravel water temperature in section 1-1 was 5.78° C while the average in-water temperature in section 1-2 was 5.76 ° C. The maximal absolute daily temperature difference between in-gravel and in-water temperatures was 0.14° C while the average difference equaled 0.03° C. The highest daily average temperature recorded during the incubation period was 13.56° C and occurred on 30 September while the lowest of 1.19°C was observed on 12 December.

Gravel Composition

The results of the gravimetric analyses made on gravel samples collected in the observation stream in 2000 and 2001 are shown in Table 4. Three parameters, the geometric mean of gravel particle size (D_g), the percentage of material less than or equal to 2 mm in diameter ("fines") and a Fredle Index (Lotspeich and Everest 1981) value were calculated on each sample. Each of these statistics has been previously correlated with egg-to-fry survival values in salmonids. In general egg-to-fry survival rates increase as D_g values rise and percent fines decrease (Chapman 1988). Lotspeich and Everest (1981), however, showed that gravel mixtures with similar D_g values could possess varying amounts of fine sediments. Therefore they state that just using D_g values to estimate expected survival rates may be misleading because other factors such as pore size and permeability also affect salmonid survival. To account for gravel size composition and the occurrence of fines they developed the Fredle Index that equals the D_g of a sample divided by a sorting index or S_o developed by Krumbein and Pettijohn (1938). Gravels possessing Fredle index values greater than 5 appear to provide optimal egg to fry survival conditions (Lotspeich and Everest 1981; Chapman 1988).

The gravel mixture that was developed for the observation stream was expected to have a D_g of 31 mm, no fines, and a Fredle Index value of 22. As Table 4 shows the material used in the stream had a mean D_g of 19.9 mm, possessed fines (1.1%) and had a mean Fredle Index value of 11.3. Once the stream had been in operation for an incubation season the mean Fredle index (7.6) and D_g value (15 mm) fell while the percentage of fines in the channel increased to 1.65%. Cleaning the channel did not noticeably affect either the mean Fredle (7.6) or D_g (14) values but it did reduce fines to 1.1%.

Table 4. The geometric mean particle size, percent fines, and Fredle Index values obtained from gravel samples removed from the observation stream before fish introduction in 2000, immediately after emergence in 2001, and after cleaning in 2001.

Prior To Adult Introduction: August 2000				
Stream Section	No. Of Observations	Geometric Mean (D_g) Of Particle Sizes	% Of Particles <2 mm	Fredle Index Value
1-1	3	19.3	0.90%	10.0
1-2	3	17.1	1.80%	7.7
1-3	3	21.4	1.10%	10.2
2-1	3	20.2	0.77%	10.6
2-2	3	21.7	1.23%	11.6
2-3	3	23.7	0.83%	13.5
Overall Mean		20.6	1.11%	10.6
After Fry Emergence: June 2001				
1-1	4	13.3	3.80%	6.4
1-2	6	14.1	2.15%	8.3
1-3	2	16.0	0.55%	7.6
2-1	3	17.4	1.50%	8.9
2-2	3	16.1	1.27%	6.5
2-3	4	14.1	0.65%	8.0
Overall Mean		15.2	1.65%	7.6
After Cleaning: August 2001				
1-1	7	15.0	1.37%	8.0
1-2	5	14.5	1.12%	7.0
1-3	5	14.8	1.42%	8.4
2-1	6	14.2	0.82%	7.8
2-2	7	13.1	0.71%	7.2
2-3	6	12.8	0.97%	7.3
Overall Mean		14.1	1.07%	7.6

Biological Traits And Behavior Of The Fish Placed Into the Observation Stream in 2000

On 20 September 2000, twelve females, thirteen males, and three jacks were placed into the Observation Stream. Table 5 presents the biological information obtained on each of these fish just before they were placed into the stream.

Table 5. Biological attributes of the spring chinook placed into the observation stream in 2000.

Date Tagged	Age	Tag No.	Weight (Kilos)	Fork Length	Condition[1]	Estimated Fecundity	Eggs Lost At Tagging
Females: Section 1-1							
20 Sep	4	YY00	3.569	715	Good	3674	61
20 Sep	4	YY01	4.280	755	Injured/Poor	4453	153
20 Sep	4	YY02	3.142	671	Excellent	3284	13
20 Sep	4	YY03	3.105	660	Good	3098	6
20 Sep	4	YY04	3.538	705	Good	3972	5
20 Sep	4	YY05	3.798	705	Good	4343	6
20 Sep	4	YY06	3.403	715	Excellent	3965	7
20 Sep	4	YY07	3.789	731	Excellent	4081	16
Females: Section 1-2							
20 Sep	4	YY08	4.027	729	Excellent	4145	9
20 Sep	4	YY09	3.508	687	Good	3573	2
20 Sep	4	YY11	3.565	695	Excellent	3499	4
20 Sep	4	YY12	4.284	734	Excellent	4379	3

Date Tagged	Age	Tag No.	Weight (Kilos)	Fork Length	Condition[1]	Estimated Testes[2] Weight (g)
Males: Section 1-1						
20 Sep	4	WW00	3.590	741	Good	185.9
20 Sep	4	WW01	2.902	708	Excellent	156.3
20 Sep	4	WW02	3.108	711	Excellent	165.2
20 Sep	4	WW03	4.603	788	Good	229.5
20 Sep	4	WW04	3.716	738	Good	191.4
20 Sep	4	WW05	5.092	823	Excellent	250.6
20 Sep	4	WW06	2.057	611	Good	120.0
20 Sep	4	WW07	4.126	775	Excellent	209.0
20 Sep	3	WW08	0.849	446	Excellent	-
20 Sep	3	WW12	1.125	487	Excellent	-
Males: Section 1-2						
20 Sep	4	WW09	3.074	701	Excellent	163.7
20 Sep	4	WW13	2.589	647	Excellent	142.9
20 Sep	4	WW14	3.520	728	Excellent	182.9
20 Sep	4	WW15	4.298	794	Good	216.4
20 Sep	4	WW16	2.970	708	Excellent	159.3
20 Sep	3	WW11	1.215	505	Excellent	-

1) Condition is based on fin wear, scale loss, and fungal infestations and wounds. Excellent fish exhibit no fin erosion, scale loss or fungal infestations; Good fish show slight wear in the caudal fin and anal fin and no scale loss or fungal infestation. Fair individuals have obvious fin erosion, some scale loss, and patches of fungal growth. Poor individuals show extensive fin wear, patches of fungus, and scale loss.
2) Testes weights were estimated by using the following linear regression formula that was obtained from upper Yakima River spring chinook. Testes weight = 31.5 + ((0.043)(body weight in grams). This relationship was established for 4-yr-old males and may not be valid for jacks (3-yr-old). Therefore no testes weight predictions were made for jacks.

<u>Redd Locations And Sizes</u>

Females quickly recovered from being tagged and anesthetized and within hours some had established territories and spawned. For example, femalesYY03, YY11, and YY12 spawned within four to five hours after being tagged. In fact eight of the 12 females established territories and began nest digging six hours or sooner after being placed into the stream (Table 6). In less than 24 hours all the females that established territories had done so. One of the females (YY01) died less than two hours after being released. As Table 5 indicates she was considered to be in poor condition when she was tagged and in retrospect was not a good candidate for the stream. Another female YY04 lived for a longer period, but may have only spawned once. She dug and was seen in a location with a developing nest but was not observed to spawn or to be linked to a location for an extended period.

Table 6. Amount of time that elapsed between tagging and the establishment of a territory and the occurrence of a first spawning in the females placed into the observation stream in 2000.

Female Tag No.	Stream Section	Time Before Territory Establishment	Time Before First Spawning
YY03	1-1	3 hr 27 min	4 hr 23 min
YY05	1-1	2 hr 57 min	Not Observed
YY07	1-1	2 hr 31 min	Not Observed
YY00	1-1	5 hr 15 min	Not Observed
YY06	1-1	Established by day 2	Not Observed
YY02	1-1	Established by day 2	Not Observed
YY04	1-1	Established by day 2	Not Observed
YY11	2-1	2 hr 22 min	3 hr 49 min
YY12	2-1	2 hr 36 min	4 hr 29 min
YY09	2-1	3 hr 55 min	Not Observed
YY08	2-1	6 hr 40 min	Not Observed

By September 22 all the females appeared to be through with their spawning activities. Maps were made of the location and extent of each female's territory and methods described by Welch (1948) were used to estimate the surface area of each redd. Every female constructed a single redd and instantaneous female density had a clear effect on redd size. Females spawning in section 1-1 where eight females had been placed had an average territory size of 3.6 square meters while the mean redd size of the females liberated into section 1-2 equaled a little over 9 meters squared (Table 7). Water velocities associated with the redd sites ranged from 1.25 fps to 2 fps. The lower ends of each section, just anterior to the openings in the downstream cross weirs, were the first locations chosen by females in each section. Females establishing territories later on chose areas that were upstream and had higher water velocities (Table 8).

Table 7. Redd sizes of the females placed into sections 1-1 and 1-2.

Female Tag No.	Stream Section	Maximum Length (m)	Maximum Width (m)	Total Area (m^2)
YY03	1-1	2.67	1.81	3.76
YY05	1-1	2.96	1.58	3.03
YY07	1-1	2.78	2.14	5.01
YY00	1-1	2.96	1.32	3.37
YY06	1-1	4.08	1.32	3.18
YY02	1-1	3.34	1.15	3.10
YY04[1]	1-1	-	-	-
YY08	1-2	4.63	2.14	7.15
YY09	1-2	4.45	2.64	8.14
YY11	1-2	6.84	2.47	12.58
YY12	1-2	5.30	2.14	8.24

1) Female YY04 was observed digging in a portion of female YY03's redd. Measurements of the area she may have disturbed were not taken because of the difficulty of separating her activities from those produced by female YY03.

Table 8. The water velocities associated with redd locations in section 1-1.

Female Tag Number In order of Territory Establishment[1]	Grid Location[2]	Water Velocity in m/sec and feet/sec)
YY03	C-4	0.38 m/sec (1.25 fps)
YY05	E-2	0.43 m/sec (1.42 fps)
YY07	E-4	0.39 m/sec (1.29 fps)
YY00	E-3	0.40 m/sec (1.30 fps)
YY04	C-4	0.44 m/sec (1.43 fps)
YY06	B-2	0.61 m/sec (2.00 fps)
YY02	D-2	0.49 m/sec (1.60 fps)

1) Females 03, 05, 07, and 00 established redds within hours of being introduced into the observation stream while females 04, 06, and 02 were not observed on a territory until the first observation period of day two. These three fish clearly became territorial during the night of September 20 or early morning of the 21st.
2) The location of each grid section can be seen in Fig. 3.

Longevity

The average lifetime of a male placed into the observation stream was 5.9 days (range 1.2 to 9.1 days). Jacks (3-yr-old males) appeared to live slightly longer (mean of 7.4 days; range 5 to 9.1 days), however, since only three were placed into the observation stream it is difficult to assess whether a biological difference in longevity exists between them and older males. A Kruskal-Wallis one-way analysis of variance of ranks (Siegel 1956) showed that females tended to live for shorter periods than males ($H = 5.96 > 3.84$, alpha 0.05). Their in-stream lifetimes ranged from 1.9 to 5.3 days and averaged 3.7 days. Additional Kruskal-Wallis tests were performed to determine whether females placed into section 1-1 (high instantaneous density, 8.7 m^2/female) had similar lifetimes to those introduced into section 1-2 (low instantaneous density, 17.4 m^2/female). The null hypothesis that section or instantaneous density had no effect on stream life could not be rejected ($H = 0.038 < 3.84$, alpha 0.05). A similar test was performed on data collected from the males placed into these two sections. As in the case of females, males placed into both sections had similar in-stream longevities ($H = 1.29 < 3.84$, .05 alpha). The length of time a female lived in the channel did affect how successful she was in depositing her eggs. Those fish that lived for more than 2 days deposited 90% or more of their eggs while those that lived for a shorter period of time were usually not as successful. Conversely, males that had long stream lives were not always those that were reproductively successful. For example, a Spearman Rank correlation (Siegel 1956) that examined the relationship between male longevity and the percentage of fry fathered was performed on fish placed into section 1-1. The "rs" value obtained (-.414) was non-significant. Longevity data and other post mortem information collected on each fish placed into the observation stream are presented in Table 9.

Nuptial Color Patterns

The nuptial coloration patterns extant on mature spring chinook are quite dynamic and variable. Generally the fish have a uniform tan to light brown background color covered with elliptically shaped back spots. Once the fish began interacting with one another new color patterns emerged which were placed into three major types referred to as stripe, golden, and black. Fish classified as having the stripe pattern had light tan or green backs, a single broad dark purple-black stripe that began in the opercle and ran across the entire lateral surface of the fish ending at the terminus of the caudal peduncle. The ventral surface of these fish was often gray or white. Fish possessing the golden pattern were a uniform gold to tan that was covered with distinct spotting. No sign of a stripe was evident on their lateral surfaces. Black fish were uniformly dark brown or black; on occasion some spotting was evident. A few of the fish (both sexes) exhibited red hues on their backs and sides, this color took the place of the usual tans or browns that most of the fish had. Such fish could adopt all three general color patterns the only difference being the presence of a general reddish brown background color.

Prior to establishing a territory, females often had the gold pattern, once they began to defend a location and commence on nest construction; many of them adopted the stripe pattern. Dominant or alpha males usually had the black pattern while males that were not associated with females often had the gold pattern. Satellite males (fish associated with a spawning pair but located downstream of the courting or alpha male) or males that were often chased by males and females often exhibited the stripe pattern. These observations are reified in Table 10 that depicts the relationships between social status and the color patterns exhibited by the fish. Our observations made it clear that fish can quickly shift their color patterns depending on their social circumstances. Gold fish may darken their

Table 9. Longevity and additional post-mortem data collected on spring chinook placed into the Observation Stream in 2000.

Females: Section 1-1						
Tag No.	Longevity In Hours	Weight (Kilos)	Length (Fork mm)	Egg Retention	AED	Percent Spawned
YY00	102.3	2.766	701	262	3412	92.9%
YY01[1]	-	-	-	-	-	0.0%
YY02	119.3	2.402	662	1	3283	99.7%
YY03	45.1	2.449	662	314	2784	89.9%
YY04	45.1	3.438	710	3187	785	19.7%
YY05	102.3	2.953	685	65	4278	98.5%
YY06	102.3	2.602	707	3	3962	99.2%
YY07	102.3	2.884	725	4	4077	99.9%
Females: Section 1-2						
YY08	76.3	3.253	725	442	3703	89.3%
YY09	76.3	2.689	690	257	3316	92.8%
YY11	127.3	2.441	680	0	3499	100.0%
YY12	76.3	3.315	725	6	4373	99.9%
Males: Section 1-1						
Tag No.	Longevity In Hours	Weight (Kilos)	Length (Fork mm)	Testes Weight (g)	% Testes Depletion	Testes Coloration
WW00	146.8	3.502	720	194.9	-4.8%	White
WW01	218.2	2.770	705	122.7	21.5%	White & pink
WW02	119.3	2.927	705	94.1	43.0%	White & red
WW03	102.3	4.175	770	49.2	78.6%	Red
WW04	192.4	3.501	737	163.3	14.7%	White some pink
WW05	76.3	4.780	818	132.0	47.3%	Red
WW06	127.3	1.891	606	83.4	30.5%	White some pink
WW07	218.2	3.915	765	116.7	44.2%	White & pink
WW08	192.4	0.797	440	24.2	-	White & pink
WW12	218.2	1.016	485	30.5	-	White & pink
Males: Section 1-2						
WW09	192.4	2.844	665	95.5	41.7%	Uniform pink
WW13	193.4	2.390	645	85.5	40.2%	White & pink
WW14	27.7	3.475	720	96.1	47.5%	Red & white
WW15	102.3	4.188	785	114.6	47.0%	White & pink
WW16	50.3	2.939	710	89.1	55.9%	White
WW11	119.3	1.132	499	41.6	-	White

1) Female YY01 died approximately two hours after being placed into the channel and therefore no post-mortem data were collected on this individual

sides and lighten their ventral and dorsal surfaces and thus move into the stripe pattern. Conversely, fish with the gold pattern may darken all their surfaces and adopt the black pattern. Fish with stripes can lose them and move into the gold or black categories.

Table 10. The relationship between nuptial color patterns in spawning spring chinook salmon and their social status.

Social Status of The Observed Fish	Stripe Pattern	Gold Pattern	Black Pattern
Color patterns of males attacked by females	87.5%	6.25%	6.25%
Color patterns of alpha males	3.7%	14.8%	81.5%
Color patterns of territorial females	90.4%	0.0%	9.6%

Linking Reproductive Success With Behavioral And Morphological Traits

One of the objectives of the work done in 2000 was to ascertain whether behavioral traits observed during daylight hours could be used to estimate the relative reproductive success of each fish placed into the observation stream. To accomplish this objective, two tasks had to be completed. First, the reproductive behavior of each individual in the observation stream had to be monitored and categorized. And, second an estimate of the number of offspring each of these fish produced had to be made. The focused and scan observations were used to characterize the reproductive behavior of each fish. Estimating the number of fry produced by each individual was accomplished by: 1) randomly removing approximately ten percent of the fry produced from each section, and 2) linking the micro-satellite DNA signatures of the sampled fry to the adult fish placed in the channel.

Altogether 24,922 fry emerged from the channel giving it an overall egg-to-fry survival value of [(24,922 captured fry)/(37,469 deposited eggs)] of 66.5%. The modified fyke nets and live boxes placed at the ends of sections 1-1 and 1-2 were inspected daily from February 8 through May 4 2001. Emergence began after the fry had experienced 811 Temperature Units C^{o}, reached the 50% point at 1088 TU's, and was finished after 1300 TU's had been accumulated. The number of fry captured on each day in the sections is shown in Fig. 5. Unfortunately, the fry nets developed holes in their bottom panels sometime during the emergence period. Apparently, as water dropped from one section to the next it forced the bottom of the nets to be repeatedly rubbed up and down on the substrate which eventually wore portions of the net out. Because of these leaks the egg-to-fry survival value presented above is probably a conservative estimate.

The leaks in the nets allowed fry that had been produced from section 1-1 to enter section 1-2 and for fry produced from both of these sections to enter section 1-3 and to possibly exit the stream without being counted or sampled. Eleven thousand seven hundred and seventy-six fry were caught in section 1-1 and twelve thousand one hundred and fourteen were captured in section 1-2. An additional 1,032 fry were caught in section 1-3 in May after the leaks had been discovered. A total of 1,214 fry from section 1-1, 1,241 individuals from section 1-2, and 104 fry from section 1-3 were removed for DNA analyses. To date, 774 individuals sampled from section 1-2 have been analyzed and assigned to parental fish. The remaining samples of fry from sections 1-1 and 1-3 have been genotyped but have not yet been linked to parental fish. Out of those 774 fry, 554

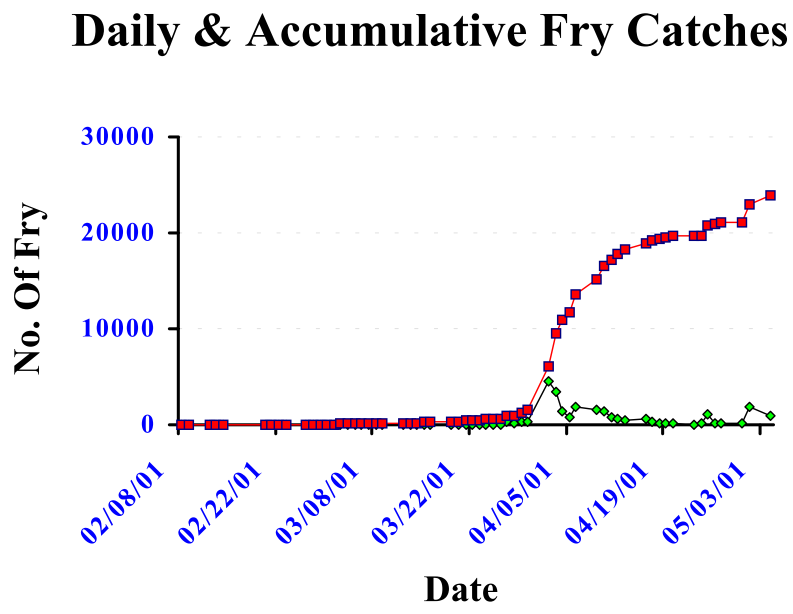

Fig. 5. The daily and accumulative catches of spring chinook fry captured in the live boxes located at the ends of sections 1-1 and 1-2.

were linked to the adults placed into section 1-2 while the remaining 220 originated from the adult fish placed into section 1-1.

In Table 11 the results of the DNA pedigree analyses done on the 774 fry are presented. Information on the adults placed into section 1-1 should be regarded with caution because so few fry (220) from this population have been analyzed. Conversely, the data presented on the adults placed into section 1-2 represent a truer picture of actual offspring production. In both sections, it is clear that variation in male reproductive success (i.e. the capacity to produce offspring) is much greater than that experienced by females. For example, in section 1-2, one male (WW09) spawned with every female and was responsible for fathering almost 80% of the fry produced from that channel section, while other males in 1-2, e.g. WW14, WW15, and WW11, apparently produced no viable offspring. In addition, while the adults were being observed, a precocial male was seen spawning with a larger anadromous pair. This individual had migrated into the observation stream, from the adjacent oxbow and had somehow jumped over 30 cm high falls and negotiated its way through a picket barrier before arriving in 1-2. The DNA pedigree analysis shows that this fish also spawned with all the females in section 1-2. It obtained significantly fewer fertilizations than WW09 but it was more reproductively successful than some of its larger competitors. Another precocious male managed to gain

Table 11. Results of the micro-satellite DNA pedigree analyses performed on fry sampled from the observation stream. Each value in the body of the table represents the number of fry produced by a particular male x female cross.

Section 1-1 (Results From 220 Fry)

Female Tag No.	Male Tag No.											Totals	% Of Total
	05	03	02	06	00	04	08[1]	01	07	12[1]	Unk[2]		
YY03	3	3	0	0	0	6	0	0	0	0	1	13	5.91
YY04	0	0	0	0	0	0	0	6	0	0	0	6	2.73
YY06	12	10	0	0	0	1	4	0	0	5	0	32	14.55
YY07	74	0	0	0	0	14	0	0	0	0	0	88	40.00
YY05	1	6	4	0	0	16	0	0	0	0	0	27	12.27
YY00	15	2	2	0	0	0	0	0	0	0	0	19	8.64
YY02	28	5	0	0	0	1	0	0	0	0	1	35	15.91
Totals	133	26	6	0	0	38	4	6	0	5	2	220	
% Of Total	60.5	11.8	2.7	0.0	0.0	17.3	1.8	2.7	0.0	2.3	0.9	100.0	

Section 1-2 (Results From 554 Fry)

Female Tag No.	Male Tag No.							Totals	% Of Total
	14	16	15	11[1]	13	09	Unk[2]		
YY12	0	0	0	0	0	125	11	136	24.6
YY09	0	0	0	0	23	89	1	113	20.4
YY08	0	0	0	0	0	137	1	138	24.9
YY11	0	62	0	0	9	91	5	167	30.1
Totals	0	62	0	0	32	442	18	554	
% Of Total	0.0	11.2	0.0	0.0	5.8	79.8	3.3	100.0	

Estimated Number of Fry Produced By The Females Placed Into Section 1-1

Female Tag No.	Estimated # Of Fry/Female[3]	Actual Egg Deposition	Potential Egg Deposition	% Survival AED	% Survival PED
YY12	2302	4373	4379	52.6	52.6
YY09	1912	3316	3573	57.6	53.5
YY08	2335	3703	4145	63.1	56.4
YY11	2826	3499	3499	80.8	80.8

Estimated Number of Fry Produced By The Males Placed Into Section 1-2

	Male Tag Number						
	WW14	WW16	WW15	WW11	WW13	WW09	Unk[2]
Estimated No. Of Fry	0	1,049	0	0	542	7,480	305

1) Jacks
2) Precocial males, one spawned in section 1-1 and another spawned in section 1-2
3) Fry estimates were made by multiplying the % of the sample originating from a fish by 9,375.43 the estimated number of fry produced from section 1-2.

entrance into section 1-1. As Table 11 shows, it too was able to spawn with several females and produce offspring. Also, during our daylight observations, we never noticed jacks associated with females in either section. Yet, the pedigree analysis shows that the two jacks (WW08 and WW12) in section 1-1 spawned at least once with the same female (YY06).

Unlike males, all the females placed into the observation stream produced offspring. For example, the four placed into section 1-2 all achieved 50% or higher egg-to-fry survival rates and each fish generated between 1,900 to 2,800 fry. The pedigree information so far obtained for section 1-1 is not complete enough to estimate egg-to-fry survival rates for the females in this section. However, fry from all seven females spawning in this section were found to be present in the 220 fry sample that was analyzed.

Because so few fry from section 1-1 have yet to be assigned to adult fish our effort to compare reproductive behavior with offspring production has been restricted to section 1-2. The most successful female in this section, YY11 was the first to establish a territory and spawn, had the largest redd, and lived the longest. Female YY08 was the next most successful female. She took the longest to establish a territory, had the smallest redd in this section, and lived for the same amount of time as two of the other females did. This female was also subject to numerous attacks by female YY09. These attacks may have prevented her from completely spawning as she retained 447 eggs. She was however, able to deposit an estimated 3,703 eggs and 63% of these survived to the fry stage. Thus even though these two females had slightly divergent behavior both were successful at converting more than half of their eggs into fry. Intra-sexual competition for space among the females in this section was low and therefore each fish was able to quickly establish a territory and successfully spawn. Egg retention data, however, indicated that females YY08 and YY09 might experience lower PED-to-fry survival rates than females YY11 and YY 12 simply because they were not as successful at depositing eggs. The DNA pedigree results showed that these females and female YY12 had comparable PED-to-fry survival values even though they had retained several hundred eggs. In general, it appears that behavioral observations can be used to produce a gross estimate of female reproductive success. If a female cannot establish a territory, or is unable to complete all of her nests and therefore retains a large quantity of eggs (>1000) she will not be as successful as a fish that is able to accomplish these tasks.

The pedigree analysis that measured the reproductive success of the males in section 1-2 indicated a great deal of variation existed in the ability of individuals to produce offspring. Behavioral observations made on these fish also reflected major differences in their capacities to court females and spawn. Table 12 summarizes the behavioral data collected on each male. The first column, labeled "Male Dominance" is the percentage of attacks a male initiated against potential rivals. The higher the dominance value the more often a male attacked adjacent fish. The next column shows the percentage of all the attacks a male received that originated from females. These data potentially reflect two female responses. In one instance, females may be expressing mate choice and are using attacks to drive away males that they find unattractive. Alternatively, such attacks may represent efforts to defend nests from individuals having the stripe color pattern. As Table 10 illustrates most territorial females have this color pattern and it clearly pays females to chase other females from their nest sites since such fish may dig and destroy some of their recently deposited eggs. The next column shows the percentage of time a male was observed having the stripe pattern and the last two columns indicate the number of times an individual was observed in close proximity to a female and the number of times he was observed spawning.

Table 12. Dominance ranking of the males placed into section 1-2 based on five spawning behavior attributes.

Tag No. Of Male	Male Dominance[1]	Incidence of Female Attacks[2]	% Of Observations Male Had Stripe Pattern	No. Times Observed Next To A Female	No. Of Observed Spawnings	Overall Rank[3]
YY09	97.1%	0.0%	0.0%	26	4	1
YY16	30.7%	2.8%	0.0%	20	2	2
YY13	58.1%	6.9%	21.0%	14	2	3
YY15	6.7%	13.3%	50.0%	6	0	4
YY11	4.2%	29.0%	100.0%	2	0	5
YY14	0.0%	12.5%	100.0%	1	0	6

1) Percentage of the time a male initiated an attack on potential rivals
2) Percentage of time a male was attacked (chased, rammed or bitten) by a female
3) Male rank represents an attempt to reify the behavioral observations in a single relative value

The data in Table 12 have been arranged in a hierarchal fashion; that is information associated with the most dominant individual was placed in the first row. Each row thereafter shows the behavioral traits of the next most dominant male. The table is an attempt to use behavioral traits to generate ordinal or ranking data on each fish. Such relational data indicates that one individual is apparently greater than another but the degree of difference is not clearly elucidated. When the ranked values in this table are compared to the information shown in Table 11 a strong positive relationship can be seen. The males that were ranked highest behaviorally also produced the greatest number of fry. The behavioral rankings were done prior to obtaining the pedigree analyses and therefore represent and independent assessment of male reproductive success. However, as indicated above, behavioral traits by themselves cannot be used to assess absolute differences in offspring production. In addition, the DNA pedigree work was able to shed light on spawning events that were not observed, probably because they took place at night. For instance, as previously mentioned, jacks were rarely seen with females and it was assumed that they had not spawned. The DNA based pedigree analysis, however showed that the two jacks present in section 1-1 did spawn at least one time. In addition, the precocious male in section 1-2 was observed participating in a single spawning yet the pedigree data showed that this same fish spawned at least three more times. Nonetheless, the behavioral data collected on the males placed into section 1-2 did provide a coarse estimate of the relative reproductive success of each male.

DISCUSSION

During the spring and summer of 2000 an observation stream was constructed on the grounds of the Cle Elum Hatchery. Wild spring chinook native to the upper Yakima

River were introduced into the structure in September of 2000 for four major purposes. First, to determine if the fish would spawn under the environmental conditions present in the structure; second to examine how two instantaneous female densities (8.7 and 17.4 m^2/female) affected intra-sexual competition among females for space; third to establish whether observations made on adult fish could be linked to their capacity to produce offspring; and fourth to discover if eggs deposited in the channel would survive and produce fry.

The adult fish placed into the channel readily spawned. Care was taken to provide the fish with a physical environment that would meet their criteria for spawning locations. For instance, each section possessed areas with water depths and velocities that spring chinook are known to prefer (Bjornn and Reiser 1991). In addition, an attempt was made to provide the fish with substrate materials they could readily excavate and use for redd locations. The pumping and water supply system worked well except for one occasion that took place at the very end of the incubation season. When new fry are added to the hatchery's raceways in late April and early May spring water is pumped into the raceways. Up to that time, river water had been used in the observation stream. When the transition from river water to spring water occurred not enough water was immediately available and flow into the observation stream ceased for at least an hour. This interruption did not cause any noticeable effects as no fry mortalities were seen in the stream or in the live boxes placed at the end of sections 1-1 and 1-2. Hatchery personnel devised a more gradual procedure that was designed to prevent this from happening again. However, a similar episode occurred in 2001, and thus additional changes in the water transition procedure have been made (Dan Barrett, personal communication).

Generally, the fish used in the observation stream exhibited nest building, courting, and agonistic behavior that was comparable to what has been observed on spring chinook spawning in the upper Yakima River (Schroder and Knudsen unpublished data) and elsewhere (Neilson and Banford 1983). However, fish spawning in the upper Yakima did engage in prolonged chases that were 20 or more meters in length. Additionally, females in the Yakima River occasionally abandoned nest sites for 30 minutes or more when masculine competition in their redd area became intense. When this occurred they did not simply drift downstream for several meters, instead they often completely disappeared from view, traveling many meters away from their spawning location. The 15 m long x 4.6 meter wide sections in the observation stream prevented the fish from expressing these types of behaviors. Consequently, in 2001 and 2002 we created two 45.7 m long by 4.6 m wide sections by removing pickets between the three upper (1-1, 1-2, and 1-3) and three lower (2-1, 2-2, and 2-3) sections. These longer sections provided the fish with opportunities to interact with one another in ways that were typical to those that occurred on natural spawning grounds.

Unlike a production-spawning channel, the observation stream was not designed nor operated to maximize survival. It was built to provide an arena where the spawning behavior and production of progeny from hatchery- and wild origin fish could be directly compared. One factor that can strongly affect the reproductive success of a female is the number of females in her spawning area that are territorial or attempting to establish a territory (instantaneous female density). When female instantaneous densities are high (e.g. less than 1 m^2/female in chum salmon; Schroder 1973) egg retention and redd superimposition both increase. At such densities some individuals are prevented from establishing territories or are forced to begin nest construction activities after they have expended large amounts of energy on fending off attacks of territorial females and in searching for suitable spawning locations. Fish exposed to these kinds of stresses often retain large numbers of eggs (Schroder 1973). We wanted to create a social environment in that would promote intra-sexual competition among females because it was felt that subtle differences between hatchery and wild fish would be expressed when competition for spawning locations occurred.

Bjornn and Reiser (1991) summarized the redd sizes that have been observed in spring chinook by past investigators and they appear to be around 3 to 4 square meters. These values represent the gravel areas that individual fish have disturbed but likely underestimate the area they may attempt to defend. In the observation stream, for instance, females were seen chasing, ramming and biting females that were 3 meters or more away from the center of their redds. Such behavior creates a halo effect around each redd and effectively reduces the space that non-territorial females may have available for nest locations. In addition, our flow measurements suggested that about half of each section had water velocities that were lower or higher than those preferred by this species. Consequently the females in section 1-1 had a probable instantaneous density of 4 m^2/female while the density experienced by females in section 1-2 was most likely 8 m^2/female. The females placed into the high-density section (1-1) had redd territories half the size of the fish spawning in the low-density section (1-2). Furthermore, the borders between redds in section 1-1 often overlapped while those in section 1-2 did not. Egg retention was also a little higher in section 1-1. Given these differences we concluded that allotting 8 females per section would provide a suitable amount of competition among females to detect differences in their capacity to establish territories and spawn successfully. Particularly since intense agonistic interactions were observed to occur even among the females placed in the section (1-2) that had just four females competing for space.

The behavioral observations made on the fish were positively linked with the results obtained from the micro-satellite DNA pedigree analyses. However, as previously mentioned, these observations could only provide a relative rank in reproductive success in the males. Observations made on females were also somewhat limited. Redd location and size, and the number of males that an individual spawned with could be determined by visual observation. However, how well deposited eggs survived to the fry stage could only be discerned by capitalizing on the genetic signatures of the fry. Not knowing this value limits any reproductive success evaluation that can be performed on females. Moreover, some spawnings that were detected by the pedigree analysis were not seen probably because they occurred during darkness. The post-mortem inspections made on the fish did provide some important ancillary information, for example, the amount of weight each fish lost due to its spawning activities and egg retention information on each of the females. We attempted to develop an analogous spawning participation value for males by estimating their testes weights and then determining the percentage of this estimated weight that was lost during their spawning ground residency. The testes depletion values obtained on the males placed into section 1-2 were all fairly similar to one another (Table 9) even though significant behavioral and fry production differences existed among them (Tables 11 and 12). Several factors could have contributed to this finding. First, even though the fish were held in a holding pond prior to being placed into the observation stream they may have spawned in the pond prior to being tagged. Eggs were observed on the bottom of the pond and anywhere from 5 to 10% of the females used as broodstock show signs of releasing eggs in the pond before being artificially spawned. Hence testes depletion weights may not be a reliable indicator of male spawning participation. Finally, simply releasing milt does not guarantee that a male will produce any offspring since a number of males may spawn simultaneously with a female and sperm competition may preclude some from siring any offspring (Schroder 1981).

One of the chief concerns we had about the observation stream was whether the water flow and gravel composition in the structure would allow deposited eggs to survive to the fry stage. Chapman (1988) states that a number physical parameters in spawning gravels, intra-gravel flow, porosity, dissolved oxygen, and the presence of fines, can strongly affect salmon egg survival rates. The gravel mixture we requested for the channel (Table 3) contained no materials less than 4 mm in diameter. About 8% of the material actually placed in the stream violated this standard. In addition, as the structure was run, sand from the hatchery raceway was deposited in the stream. The presence of these fine materials produced a gravel mixture with an average Fredle index value of 7 instead of a value of 22 that the original mixture would have had. In retrospect the presence of these fines may prove to be beneficial since females that are unable to properly construct nests may suffer higher progeny mortality rates than those that spawn in more favorable locations or who are able to invest more time and energy on gravel cleaning activities. During the 2000-01 incubation season around 66% of the eggs deposited in the channel survived to the fry stage. The most complete information we have on the survival of eggs deposited by different females comes from section 1-2. Here three of the females achieved slightly better than 50% egg to fry survival rates. The eggs deposited by one of these females, YY11, survived at a much higher rate (~80%). This fish had the largest redd of any of the females placed in the stream and also lived the longest suggesting that some survival advantages may be obtained by the final redd mound and pot digging activities that a female engages in.

In summary, the channel proved to be an ideal location to obtain basic information on the reproductive ecology of spring chinook. The 2000 season provided us with insights on how the structure should be operated in the future. For instance, the leakage problems we encountered with the fry nets were resolved in 2001 by placing three layers of netting on the bottom panels of the nets. In addition, we used sandbags to create a pool at the end of each of the long sections we used during that season. These simple corrections prevented any fry from escaping and we were able to obtain accurate fry counts. The larger sections used in 2001 and again in 2002 provided the fish with opportunities to fully express all of their agonistic and spawning behaviors. Fortuitously plenty of genetic variation exists in this population so that the relatively new and extremely powerful DNA micro-satellite approach can be used to unambiguously assign parentage to sampled fry.

The observation stream, the capacity of collect adult spring chinook of known wild and hatchery origin, plus the capacity to employ DNA methods in pedigree analyses is providing us with the means to objectively assess the relative capacity of hatchery and wild chinook to produce progeny via natural spawning.

All the results and conclusions presented in this report should be considered preliminary in nature since the DNA pedigree analyses of the fry samples obtained originating from the adults placed into the stream have not been completely analyzed. Moreover, some of the audiotapes made on fish behavior have not been completely analyzed and hence some of the behavioral information reported here may be slightly changed once that task has been completed.

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