B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Effects of Domestication on Predation Mortality and Competitive Dominance

Yakima/Klickitat Fisheries Project Monitoring and Evaluation

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This report covers one of many topics under the Yakima/Klickitat Fisheries Project's Monitoring and Evaluation Program (YKFPME). The YKFPME is funded under two BPA contracts, one for the Yakama Nation and the other for the Washington Department of Fish and Wildlife (Contract number 00017478, Project Number 1995-063-25). A comprehensive summary report for all of the monitoring and evaluation topics will be submitted after all of the topical reports are completed. This approach to reporting enhances the ability of people to get the information they want, enhances timely reporting of results, and provides a condensed synthesis of the whole YKFPME. The current report was completed by the Washington Department of Fish and Wildlife.

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The Effects of Domestication on Predation Mortality and Competitive Dominance

Yakima/Klickitat Fisheries Project Monitoring and Evaluation

Annual Report 2004

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Executive Summary

Raising fish in hatcheries can cause unintended behavioral, physiological, or morphological changes in chinook salmon due to domestication selection. Domestication selection is defined by Busack and Currens 1995 as "changes in quantity, variety, or combination of alleles within a captive population or between a captive population and its source population in the wild as a result of selection in an artificial environment. Selection in artificial environments could be due to intentional or artificial selection, biased sampling during some stage of culture, or unintentional selection (Busack and Currens 1995). Genetic changes can result in lowered survival in the natural environment (Reisenbichler and Rubin 1999). The goal of supplementation or conservation hatcheries is to produce fish that will integrate into natural populations. Conservation hatcheries attempt to minimize intentional or biased sampling so that the hatchery fish are similar to naturally produced fish. However, the selective pressures in hatcheries are dramatically different than in the wild, which can result in genetic differences between hatchery and wild fish. The selective pressures may be particularly prominent during the freshwater rearing stage where most mortality of wild fish occurs.

The Yakima Fisheries Project is studying the effects of domestication on a variety of adult and juvenile traits of spring chinook salmon (Busack et al. 2003). This report addresses two juvenile traits: predation mortality, and competitive dominance. Other traits will be presented in other project reports. It is anticipated that it will take at least two to five generations to detect measurable responses in many domestication response variables (Busack et al. 2003). This report addresses domestication after one generation of hatchery rearing. It is arranged into two chapters and the abstracts of these chapters are presented below. Data and findings should be considered preliminary until the results are published in a peer-reviewed journal.

Hatcheries have been used in an attempt to increase the production of Pacific salmonids in the Columbia River system since 1877. While able to achieve better survival from egg to release, it has been noted that hatchery-reared fish do not perform as well as their naturally reared counterparts in the natural environment. We performed the second year of an experiment where size-matched fry spawned from first generation hatchery broodstock and from wild broodstock were subjected to rainbow trout (*Oncorhynchus mykiss*) and torrent sculpin (*Cottus rhotheus*) predators in net pens at the Cle Elum Supplementation and Research Facility. There was no significant difference in survival between the wild origin and hatchery origin fry during 2003 (P = 0.051) or 2004 (P=0.122). Wild fry were found to have a 2.15% survival advantage over hatchery fry when 2003 and 2004 data were combined (P=0.016). Prey fish were treated identically, so any differences observed should be due to genetic changes rather than learned behavior. Although we do not know how these genetic differences will manifest in the natural environment, they will be important because in the natural environment these returning hatchery-reared offspring of wild fish are expected to spawn naturally and produce viable fry. This study will be performed annually for several generations of fish to help monitor the success of supplementation. These data should be considered preliminary until published in a peer-reviewed journal.

We tested the null hypothesis that competitive dominance among chinook salmon would not be affected by domestication selection after one generation of hatchery culture. Fish that were used in the experiments were offspring of naturally produced spring chinook salmon (wild) and offspring of spring chinook salmon that spent one generation under hatchery culture (hatchery). Both fish had grandparents that were naturally produced in the upper Yakima River. Fish were mated and reared as part of a common garden experiment. We tested two types of competitive dominance, contest and scramble. Dyadic challenges of size-matched juvenile fish were conducted for one-week trials in 80, 113.4-liter aquaria. In the contest trials, we created one highly profitable location in the aquaria. This location provided cover, food, and water velocity. Dominance was assigned to the fish that ate the most pellets within the water column, was in the preferred habitat the most, and initiated and dominated the most behavioral contests. In the scramble trials, the cover was removed from the tanks and food was introduced in unpredictable locations upon the water surface. Dominance was assigned to the fish that ate the most pellets. Wild fish dominated 4% more contests than hatchery fish when data from 2003 and 2004 were combined ($P=0.050$), but tests from individual years were not significantly different ($P>0.05$). Dominance was not significantly different in any of the scramble competition trials ($P>0.05$). Wild fish generally initiated more agonistic interactions than hatchery fish in both contest and scramble trials ($P>0.05$). There were no differences in the frequency of different types of agonistic interactions that were used by hatchery and wild fish, except that wild fish used chasing behaviors more than hatchery fish in 2003 contest trials ($P<0.05$). We also found that dominant fish grew more than subordinate fish in both contest and scramble trials ($P<0.05$). Our results suggest that offspring of first generation hatchery fish that spawn in the Yakima River will be slightly less dominant in contest competition than wild fish if the timing and size of emergence, and growth rates are similar. These data should be considered preliminary until published in a peer-reviewed journal.

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General Introduction

This report is intended to satisfy two concurrent needs: 1) provide a contract deliverable from the Washington Department of Fish and Wildlife (WDFW) to the Bonneville Power Administration (BPA), with emphasis on identification of salient results of value to ongoing Yakima/Klickitat Fisheries Project (YKFP) planning, and 2) summarize results of research that have broader scientific relevance. This is the second of a series of progress reports that address the effects of hatchery domestication on predation mortality and competitive dominance in the upper Yakima River basin (Pearsons et al. 2004). This progress report summarizes data collected between January 1, 2004 and December 31, 2004.

Raising fish in hatcheries can cause unintended behavioral, physiological, or morphological changes in chinook salmon due to domestication selection. Domestication selection is defined by Busack and Currens 1995 as, "changes in quantity, variety, or combination of alleles within a captive population or between a captive population and its source population in the wild as a result of selection in an artificial environment." Selection in artificial environments could be due to intentional or artificial selection, biased sampling during some stage of culture, or unintentional selection (Busack and Currens 1995). Genetic changes can result in lowered survival in the natural environment (Reisenbichler and Rubin 1999). The goal of supplementation or conservation hatcheries is to produce fish that will integrate into natural populations. Conservation hatcheries attempt to minimize intentional or biased sampling so that the hatchery fish are similar to naturally produced fish. However, the selective pressures in hatcheries are dramatically different than in the wild, which can result in genetic differences between hatchery and wild fish. The selective pressures may be particularly prominent during the freshwater rearing stage where most mortality of wild fish occurs.

The Yakima Fisheries Project is studying the effects of domestication on a variety of adult and juvenile traits of spring chinook salmon (Busack et al. 2003). The overall experimental design is to compare a variety of traits, across generations, from three lines of Yakima basin chinook, a hatchery control, supplementation line, and a wild control. The hatchery line was derived from wild upper Yakima broodstock and is only allowed to spawn in the hatchery. The supplementation line is upper Yakima stock that spawns in the upper Yakima River. This stock is an integration of wild and hatchery supplementation fish. Starting in 2005, we plan to use a wild control line of fish that will be the offspring of wild broodstock collected in the Naches River system, a tributary to the Yakima River. The Naches River is not stocked with hatchery fish, and there is minimal stray from Upper Yakima supplementation, so we believe that these will serve as a control to compare any genotypic changes in the hatchery and the supplementation line. As generations of fish are tested, we believe we will be able to analyze the data using an analysis of covariance to test the hypothesis that the hatchery line will exhibit greater domestication over generations, the wild line will remain at baseline levels, and the supplementation line will be somewhere in between. In this report, we have used the terms "hatchery" or "supplementation" to refer to upper Yakima fish that are progeny of fish that spent one generation in the hatchery, and "wild" to refer to fish that have had no exposure to the hatchery other than the matings for this experiment. The terms are relative to the parents that produced the fish for these experiments. All progeny of these fish were mated and reared under the same laboratory conditions.

This report addresses two juvenile traits: predation mortality, and competitive dominance. Other traits will be presented in other project reports. It is anticipated that it will take at least two to five generations to detect measurable responses in many domestication response variables (Busack et al. 2003). This report addresses domestication after one generation of hatchery rearing.

This report is organized into two chapters that represent major topics associated with monitoring hatchery domestication. Chapter 1 reports the results of domestication on predation mortality of juvenile spring chinook salmon. Chapter 2 describes the affects of domestication on competitive dominance of juvenile spring chinook salmon. The chapters in this report are in various stages of development and should be considered preliminary unless they have been published in a peer-reviewed journal. Additional field work and/or analysis is in progress for topics covered in this report. Throughout this report, a premium was placed on presenting data in tables so that other interested parties could have access to the data. Readers are cautioned that any preliminary conclusions are subject to future revision as more data and analytical results become available. Data and findings should be considered preliminary until the results are published in a peer-reviewed journal.

Acknowledgments

We would like to thank Bonneville Power Administration, particularly David Byrnes, for financially supporting this work. In addition, we could not have completed this work without the help and support of many individuals during 2003 and 2004. Most of these individuals are recognized on title pages or in acknowledgments of various chapters in this report.

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Chapter 1

The Effects of Domestication on the Relative Vulnerability of Hatchery and Wild Spring Chinook Salmon to Predation

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Abstract

Hatcheries have been used in an attempt to increase the production of Pacific salmonids in the Columbia River system since 1877. While able to achieve better survival from egg to release, it has been noted that hatchery-reared fish do not perform as well as their naturally reared counterparts in the natural environment. We performed the second year of an experiment where size-matched fry spawned from first generation hatchery broodstock and from wild broodstock were subjected to rainbow trout (*Oncorhynchus mykiss*) and torrent sculpin (*Cottus rhotheus*) predators in net pens at the Cle Elum Supplementation and Research Facility. There was no significant difference in survival between the wild origin and hatchery origin fry during 2003 ($P = 0.051$) or 2004 ($P=0.122$). Wild fry were found to have a 2.15% survival advantage over hatchery fry when 2003 and 2004 data were combined ($P=0.016$). Prey fish were treated identically, so any differences observed should be due to genetic changes rather than learned behavior. Although we do not know how these genetic differences will manifest in the natural environment, they will be important because in the natural environment these returning hatchery-reared offspring of wild fish are expected to spawn naturally and produce viable fry. This study will be performed annually for several generations of fish to help monitor the success of supplementation. These data should be considered preliminary until published in a peer-reviewed journal.

Introduction

Hatcheries have been used in an attempt to increase the production of Pacific salmonids in the Columbia River System since 1877 (Lichatowich 1999). Early hatcheries were not built to increase natural production but to increase commercial catch. More recently, hatcheries have been seen as a way to bolster natural production by increasing survival to the smolt stage, though it has been noted that hatchery-reared fish do not perform as well as their naturally reared counterparts in the natural environment (Nickelson et al. 1986; Swain and Riddell 1990). Researchers have theorized that the hatchery environment selects for certain behavioral and morphological traits that are not selected for or are repressed in the natural environment (Weber and Fausch 2003; Reisenbichler and Rubin 1999). Many of these differences acquired by hatchery-reared fish are commonly attributed to domestication, which is defined by Busack et al. (2002) as “genetic change in response to the differences between natural and anthropogenic environments”.

Research has shown that hatchery fish are not as successful at avoiding predators as their wild counterparts. Alvarez and Nicieza (2003) found that second generation hatchery brown trout (*Salmo trutta*) were less responsive to a predator than the offspring of wild brown trout reared in a hatchery and that wild caught brown trout were even more responsive than hatchery-reared wild brown trout. In addition, Yamamoto and Reinhardt (2003) found that farmed masu salmon (*Oncorhynchus masou*) fry, from a population that had been hatchery-reared for at least 30 years, were much more willing to leave cover and feed under chemically simulated predation risk than were wild-caught masu salmon.

Some studies have found evidence that these differences between hatchery and wild fish may be genetic due to differing selection pressures in the hatchery and natural environments. Berejikian (1995) found that hatchery steelhead (*Oncorhynchus mykiss*) were more vulnerable to predation by sculpins than wild steelhead reared in a hatchery and that domesticated hatchery steelhead that were previously exposed to predators were still more vulnerable to predation than wild naive fry. Johnsson and Abrahams (1991) found that laboratory reared juvenile offspring of wild steelhead were less willing to risk exposure to a predator during foraging than were juvenile offspring of wild steelhead and domesticated rainbow trout (*Oncorhynchus mykiss*) even though there was no difference in their mortality rates during standardized encounters with a predator.

The mechanisms for a decrease in survival could be physical, behavioral or both. If, for instance, the returning adult hatchery-reared fish began to produce smaller eggs (Heath et al. 2003), then their offspring would be smaller and less able to dart away from a predator (Taylor and McPhail 1985) or have a size refuge from predation (Patten 1977). If fry begin to express less innate antipredator behaviors because of relaxation of selection pressures in the hatchery environment or an increase of selection pressures that are not beneficial in the natural environment, then they will be more likely to be singled out by predators in the natural environment or more likely to take higher risks to obtain food in the presence of a predator (Johnsson and Abrahams 1991).

There is relatively little research on domestication of Chinook salmon (*Oncorhynchus tshawytscha*). To date, other research on domestication has dealt with the more traditional hatcheries that, for the most part, use hatchery origin fish for broodstock. The Cle Elum Supplementation and Research Facility (CESRF) is an intentionally integrated hatchery program where returning hatchery and naturally produced fish are allowed to spawn together in the natural environment. This integrated concept is designed to limit the consequences of domestication by allowing returning hatchery-reared fish to undergo natural selection to the greatest extent feasible. Our study is designed to monitor any effects that domestication may have on the ability of the fry to avoid predators. This study along with the other aspects of domestication selection under study can be used to adaptively manage the supplementation program if the program was found to be less successful than intended.

This chapter will report on the second year of the predator avoidance portion of our domestication studies.

Methods

Our fry were hatched in isolettes that were used for experimental crosses to gather data on other aspects of the domestication work (see Knudsen et al. 2003 for more detail on isolettes and crosses). We opted to select isolettes in a way that ensured that nearly all adult broodstock used for the experimental isolette crosses were represented in our sample at least once. All surviving fish in each isolette that was selected were used, even if there were very few. This ensured that our sample of experimental fish represented the true reproductive effort expressed by each parental cross. During 2003, we selected approximately 12,000 fry of each origin, hatchery by hatchery parents (hatchery line) and wild by wild parents (wild line), which was approximately half of the total fish contained in the isolettes. This gave us the progeny of 33 wild females, 25 wild males, 32 hatchery females, and 15 hatchery males. This accounted for 58 wild families and 59 hatchery families. During 2004, we selected approximately 8,000 fry of each origin. This gave us the progeny of 18 wild females, 18 wild males, 20 hatchery females, and 20 hatchery males. This accounted for 54 wild families and 58 hatchery families. These fish were transferred into two identical 1,710-liter polyethylene conical-bottomed circular tanks on April 17, 2003 and April 19, 2004.

All work was conducted in a 3 meter (m) by 30 m concrete raceway at the CESRF. Eight 1/8-inch nylon mesh net pens measuring 3 m long by 2.4 m wide by 1.5 m high were placed in the raceway to contain each group of trials. Net pens were totally enclosed with a zippered top. Each net pen included one 0.8 m and one 1.3 m diameter floating hoop covered with black plastic to provide overhead cover and a 1.2 m tall plastic evergreen tree to provide instream cover.

Predators were collected by backpack electrofishing and angling in area streams upstream of the CESRF water intake to minimize the potential of introducing pathogens into the hatchery facility. Each net pen received three rainbow trout and three torrent sculpins (*Cottus rhotheus*) during 2003. Two rainbow trout and two torrent sculpins were used per pen during 2004 to reduce the mortality to less than 50% and avoid density dependent selection of the predators i.e. switching to the consumption of less vulnerable individuals as the more vulnerable individuals become scarce (Fritts et al. 2003). Using fewer predators also made it possible to replace the predator assemblages periodically throughout the experimentation to avoid pseudoreplicating (Hurlbert 1984; Fritts et al. 2004).

Trials were conducted between May 19 and June 23, 2003 and May 3 and June 28, 2004 (Table 1). Each weekly trial started on Monday with the introduction of 100 hatchery and 100 wild size-matched fry. Before introduction into the net pens, all fry were anesthetized in a solution of Tricaine Methanesulfonate, measured to the nearest millimeter fork length (mm FL), and given either an upper caudal (UC) mark or lower caudal (LC) mark by incising a small amount of fin tissue from the tip of the fin. These marks were alternated between net pens and origins to eliminate any possible introduced biases between clip types. All data were entered directly onto a microcomputer and after all fry were measured and marked, students t-tests were used to make sure that there was no significant difference between the sizes of the two stocks in each net pen. If no significant difference was found, then the fry were allowed to recover before being introduced into the net pens. Each weekly trial was terminated on Friday and all surviving prey were removed, enumerated, measured to the nearest mm FL, and interrogated for marks and any bite marks that would indicate escape from a predator.

Table 1. Dates, predator replicates, and predator trial types performed during 2003 and 2004

Date Fry Stocked	Week #	Predator Set	Trial Type
5/19/2003	1	1	Mixed Origin
5/26/2003	2	1	Mixed Origin
6/9/2003	3	1	Mixed Origin
6/16/2003	4	1	Mixed Origin
6/23/2003		1	Naïve vs. Experienced
6/30/2003		1	Naïve vs. Experienced
5/3/2004	1	1	Mixed Origin
5/10/2004	2	1	Mixed Origin
5/17/2004		1	Naïve vs. Experienced
5/24/2004	3	2	Mixed Origin
5/31/2004	4	2	Mixed Origin
6/7/2004	5	3	Mixed Origin
6/14/2004	6	3	Mixed Origin
6/21/2004	7	4	Mixed Origin

Food was introduced into each net pen from Tuesday thru Thursday to ensure that weakening due to hunger did not influence survival. Feeding also introduces a situation where the fry must choose whether to increase their exposure to predation in order to feed.

The raceway and net pens were cleaned between each trial by lowering the water level, sweeping out accumulated debris, and rinsing off the net pens.

We used ANOVA to test whether the sizes of the predators we used were similar between net pens. We used the G-test of independence with the null hypothesis that the sizes of our fish had the same distribution at stocking and to test for any size differences between the survivors. We also used the G-test to test whether there were differences in the size distributions between stocking and removal. To account for growth during the five days in the net pens, 0.5 mm was subtracted from the fork length of each surviving fry before testing for size differences between stocking and removal. We used the Wilcoxon matched pairs test to test whether there were differences in the number of fry consumed between the two stock origins.

We compared the differences in survival between the hatchery and wild fry in the first exposure of fry to a predator assemblage and subsequent exposures to those predators in order to examine if there was a relationship that would indicate dependency among the predators. We believe that if there was dependency among the predators, we would see similar differences in survival, in direction, magnitude, or both, between the first exposure and subsequent exposures and that would indicate that we could not use subsequent exposures as individual replicates.

During the weeks of June 23, 2003, June 30, 2003, and May 17, 2004, we stocked each net pen with 100 naïve fry and 100 experienced fry, which were the survivors from previous trials. These trials were performed in an attempt to evaluate if there was any difference in the ability of the two crosses to increase their survival in a subsequent exposure to predators relative to each other. Any increase in survival could result from either learning avoidance behavior or the cropping of less fit individuals. There were six net pens with 200 hatchery fish, and six net pens with 200 wild fish during 2003; four net pens with 200 hatchery fish, and four net pens with 200 wild fish during 2004. Each net pen was treated as a replicate so that we had six replicates for each origin during 2003 plus four replicates for each origin during 2004 to perform the Wilcoxon matched pairs test with the null hypothesis that there was no difference between survival of naïve and experienced fish within each net pen.

Results

The sizes of all predators in all net pens were similar (Table 2) and the sizes of predators in each net pen did not vary significantly during 2003 (ANOVA; $F = 0.085$, $df = 7$, $P = 0.999$), or during 2004 (ANOVA; $F = 0.044$, $df = 31$, $P = 1.0$).

Table 2. Lengths of rainbow trout (RBT) and torrent sculpin (TSC) in each net pen at the time of stocking. Lengths are mm FL for rainbow trout and mm total length (TL) for torrent sculpin. Mean lengths of RBT and TSC are given for each net pen.

Year		Pred Set	RBT	RBT	RBT	Mean	TSC	TSC	TSC	Mean
2003	Pen 1	1	238	205	212	218.3	130	110	112	117.3
2003	Pen 2	1	198	230	194	207.3	96	103	139	112.7
2003	Pen 3	1	236	191	184	203.7	102	100	125	109.0
2003	Pen 4	1	188	205	206	199.7	105	103	111	106.3
2003	Pen 5	1	225	190	192	202.3	140	95	106	113.7
2003	Pen 6	1	200	229	190	206.3	100	92	107	99.7
2003	Pen 7	1	182	218	180	193.3	143	105	114	120.7
2003	Pen 8	1	252	225	178	218.3	140	122	106	122.7
2004	Pen 1	1	201	167		184	124	95		109.5
2004	Pen 1	2	204	162		183	113	103		108
2004	Pen 1	3	181	155		168	126.5	102		114.3
2004	Pen 1	4	245	150		197.5	114	111		112.5
2004	Pen 2	1	187	181		184	121	96		108.5
2004	Pen 2	2	175	165		170	122	105		113.5
2004	Pen 2	3	176	166		171	128	102		115
2004	Pen 2	4	246	152		199	111	114		112.5
2004	Pen 3	1	185	187		186	124	99		111.5
2004	Pen 3	2	178	161		169.5	137	106		121.5
2004	Pen 3	3	168	162		165	129	97		113
2004	Pen 3	4	216	169		192.5	113	109		111
2004	Pen 4	1	229	161		195	115	97		106
2004	Pen 4	2	189	164		176.5	115	104		109.5
2004	Pen 4	3	209	153		181	113.5	109		111.3
2004	Pen 4	4	222	169		195.5	113	114		113.5
2004	Pen 5	1	198	167		182.5	110	102		106
2004	Pen 5	2	180	165		172.5	141	105		123
2004	Pen 5	3	187	157		172	118.5	98.5		108.5
2004	Pen 5	4	229	157		193	116	107		111.5
2004	Pen 6	1	209	162		185.5	118	99		108.5
2004	Pen 6	2	166	169		167.5	121	105		113
2004	Pen 6	3	185	157		171	118.5	110		114.3
2004	Pen 6	4	192	173		182.5	119	110		114.5
2004	Pen 7	1	189	181		185	112	105		108.5
2004	Pen 7	2	166	164		165	120	104		112
2004	Pen 7	3	198	158		178	122	107		114.5
2004	Pen 7	4	191	169		180	120	106		113
2004	Pen 8	1	192	167		179.5	115	101		108
2004	Pen 8	2	182	165		173.5	120	109		114.5
2004	Pen 8	3	167	164		165.5	134.5	96.5		115.5
2004	Pen 8	4	179	174		176.5	133	102		117.5

We found no significant differences between the means (t-test, P>0.05) of the hatchery and wild fry that were introduced into the net pens in either 2003 or 2004. The size distributions of the hatchery and wild fry at introduction during 2003 differed in one of the 28 replicates (G-test, P<0.05) and differed significantly in three of the 56 replicates (G-test, P<0.05) during 2004. The means of the two origins of fish at introduction never varied by more than 0.4 mm within a net pen in 2003 (Table 3a) or more than 0.2 mm within a net pen during 2004 (Table 3b). The size distributions between the hatchery and wild fry that survived predation were significantly different in three of the 28 replicates in 2003 and three of the 56 replicates in 2004 (G-test, P>0.05). There were seven cases (12.5%) where the size distributions between stocking and removal differed significantly during 2003 and there were 34 cases (30%) where the size distributions between stocking and removal differed significantly during 2004 (G-test, P<0.05). In all the cases where there was a significant difference between stocking and removal but one, smaller sized prey were eaten at a higher rate than larger sized prey.

Table 3a. Mean fork lengths of the hatchery (H) and wild (W) fry upon stocking and removal in each net pen during the mixed origin trials in 2003.

Week	H/W	Net pen 1 In	Net pen 1 Out	Net pen 2 In	Net pen 2 Out	Net pen 3 In	Net pen 3 Out	Net pen 4 In	Net pen 4 Out
1	H					41.3	41.9	40.7	40.9
	W					41.4	41.3	40.9	42.2
2	H	42.7	42.8	42.3	42.4	42.4	43.2	42.9	43.1
	W	42.9	43.2	42.6	42.8	42.3	41.9	42.9	43.1
3	H	45	46	45.3	45.6	45.4	48.2	45.2	45.5
	W	45	46.3	44.9	44.7	45.4	48.6	45.1	45.3
4	H	45.7	47.4	46.1	47.4	47	46.6	45.9	47.3
	W	45.9	46.8	45.9	47.1	46.8	46.3	45.9	47
5	H								
	W								
6	H								
	W								
7	H								
	W								

Week	H/W	Net pen 5 In	Net pen 5 Out	Net pen 6 In	Net pen 6 Out	Net pen 7 In	Net pen 7 Out	Net pen 8 In	Net pen 8 Out
1	H	40.7	40.9	41.5	41.9				
	W	41.1	41.8	41.2	41.2				
2	H	42.7	43	42.4	42.7	43.3	43.2	42.2	43.3
	W	43	42.4	42.2	42.6	43.7	43.9	42.3	42.7
3	H	44.9	44.7	45	45.2	45.5	46.1	45.1	46
	W	44.7	44.8	45	45.2	45.3	46.1	45.1	46.1
4	H	46.7	48.2	46.3	46.8	46.5	46.8	46.8	47.4
	W	46.5	48	46.3	46.3	46.5	47.6	46.6	47.1
5	H								
	W								
6	H								
	W								
7	H								
	W								

Table 3b. Mean fork lengths of the hatchery (H) and wild (W) fry upon stocking and removal in each net pen during the mixed origin trials in 2004.

		Net pen 1		Net pen 2		Net pen 3		Net pen 4	
Week	H/W	In	Out	In	Out	In	Out	In	Out
1	H	37.2	37.9	37.4	37.4	37.6	38	37.5	37.9
	W	37.3	37.7	37.4	37.8	37.5	37.8	37.5	37.8
2	H	39	40.7	39.6	40.1	39.4	40.4	39.3	40.1
	W	39	40.5	39.6	40.3	39.4	40.6	39.3	40.5
3	H	44.2	45.3	45.1	46	45.3	46	45	46.4
	W	44.3	45.4	44.9	46	45.1	46.1	45.2	46.4
4	H	47.5	47.8	48.4	49.5	47.3	47.4	48.1	48.2
	W	47.6	48	48.5	50	47.3	48.1	48	48.2
5	H	48.9	49.5	50.5	50.9	49.8	50.6	50.2	50.7
	W	48.9	50	50.5	51.1	49.8	50.5	50.2	50.8
6	H	51.6	52	52.4	52	51.9	52.7	52	53.2
	W	51.6	52.5	52.4	52	51.9	52.9	52	53.3
7	H	53.8	54.1	54	54.5	53.5	54.7	54.7	54.9
	W	53.9	54.4	54.1	54.8	53.5	54.9	54.8	55.6
		Net pen 5		Net pen 6		Net pen 7		Net pen 8	
1	H	37.7	38.5	37.8	38.4	37.6	38.2	37.3	37.6
	W	37.6	38.2	37.7	38.7	37.6	38.2	37.6	37.8
2	H	39.4	40.8	40.3	41.3	40.1	41.2	39.8	40.9
	W	39.4	40.9	40.2	41.6	40.1	41.1	39.9	40.7
3	H	45.3	46.3	44.3	45.3	45.1	45.9	45.4	46.1
	W	45.3	46.1	44.3	45.4	45.3	46.2	45.4	46.3
4	H	47.9	48.5	48.7	49	49	49.6	47.6	48.1
	W	47.9	48.9	48.8	48.7	49	49.8	47.6	48.1
5	H	49.7	50.6	50.5	51.1	50.5	51.2	49.7	50.6
	W	49.9	50.9	50.6	51.8	50.4	51.2	50.2	51.1
6	H	52.3	52.1	52.6	52.9	53	53.1	52.2	52.9
	W	52.4	52.4	52.6	53.3	53	53.6	52.3	52.8
7	H	54.2	54.4	53.2	55	53.7	55.1	55	55.6
	W	54.1	55	53.4	55	53.9	55.5	55	55.4

For all trials combined during 2003, hatchery fish survival averaged 57%, or 57 out of 100 introduced fish, and wild survival averaged 60.1%. Hatchery fish survival was higher in ten of the 28 trials, wild fish survival was higher in 16 of the 28 trials, and survival was equal in two of the trials during 2003 (Table 4). For all trials combined during 2004, hatchery fish survival averaged 75.0%, or approximately 76 out of 100 introduced fish, and wild survival averaged 76.7%. Hatchery fish survived better in 22 of the 56 trials, wild fish had higher survival in 30 of the 56 trials, and survival was equal in four of the trials during 2004 (Table 4).

Table 4. Numbers of hatchery (H) and wild (W) fry surviving predator net pen trials at the end of each week.

Year	Week	H/W	Pen 1	Pen 2	Pen 3	Pen 4	Pen 5	Pen 6	Pen 7	Pen 8
2003	1	H			41	48	37	79		
		W			43	45	53	79		
2003	2	H	30	36	42	62	31	84	66	72
		W	38	44	58	59	49	82	67	82
2003	3	H	50	56	50	64	22	82	67	82
		W	49	68	42	70	26	89	74	75
2003	4	H	47	56	59	65	51	80	71	61
		W	54	59	51	68	49	78	66	69
2004	1	H	41	49	89	58	50	32	43	59
		W	57	35	84	62	50	31	50	51
2004	2	H	54	41	91	57	60	44	58	75
		W	71	53	92	68	60	53	53	68
2004	3	H	66	82	71	74	70	71	74	75
		W	80	81	85	86	74	76	75	83
2004	4	H	67	80	79	78	83	77	76	78
		W	74	81	80	84	65	74	80	84
2004	5	H	81	82	92	93	81	86	82	79
		W	80	84	90	91	90	73	82	89
2004	6	H	73	91	88	97	86	79	83	85
		W	89	84	89	88	85	73	81	84
2004	7	H	95	85	94	93	95	98	88	92
		W	95	91	95	94	93	92	95	88

We could not find any indication of dependency in the predators so we combined all trials during 2003 and 2004 to perform the Wilcoxon matched pairs tests in order to increase the statistical power. We found no difference in survival between the two origins in either year although all trials combined during 2003 was very close to a significant difference at the 95% level (Table 5). We found significantly higher survival of the wild fish over the hatchery fish for both years combined using all of the predator exposures (Table 5). We also found a significant difference in survival between the two origins during 2004 using only the first exposure of fry to each predator assemblage, which acted as a more conservative test (Table 5).

Table 5. Results from Wilcoxon matched pairs tests for survival between hatchery and wild fry. In all cases, mean wild fry survival was greater than mean hatchery fry survival.

		Z	N	P	Mean W-H
2003	First exposure	1.86	8	0.063	5.25
	All trials	1.96	28	0.051	3.11
2004	First exposure	1.45	32	0.147	1.97
	All trials	1.55	56	0.122	1.68
2003 & 2004	First exposure	1.98	40	0.047	2.63
	All trials	2.42	84	0.016	2.15

Naïve vs. Experienced

Experience wild fry had higher survival in four of the six trials during 2003 while experienced hatchery fry had higher survival in five of the six trials (Table 6). Experienced wild fry had higher survival in all trials while experienced hatchery fry had higher survival in three of the four trials during 2004 (Table 6). Both origins averaged higher survival after exposure to a predator during 2004 with wild origin fry experiencing a greater increase in survival relative to the hatchery origin fry (Table 7). Analysis using the Wilcoxon matched pairs test on 2003 and 2004 data combined indicates that experienced hatchery fry survived at a higher rate ($Z = 2.5$, $N = 10$, $P = 0.01$). Survival of experienced wild fry was no different from their naïve counterparts ($Z = 1.58$, $N = 10$, $P = 0.11$).

Table 6. Numbers of fry surviving in each net pen and the difference in survival (experienced minus naïve) during 2003 and 2004.

Date Stocked		Naïve	Experienced	Survival difference (exp. – naïve)
6-23-2003	Wild	65	55	-10
6-23-2003	Wild	76	34	-42
6-23-2003	Wild	40	60	20
6-23-2003	Wild	48	71	23
6-30-2003	Wild	46	73	27
6-30-2003	Wild	48	74	26
6-23-2003	Hatchery	45	78	33
6-23-2003	Hatchery	66	79	13
6-23-2003	Hatchery	54	80	26
6-23-2003	Hatchery	39	64	25
6-30-2003	Hatchery	49	79	30
6-30-2003	Hatchery	73	70	-3
5-17-2004	Wild	51	66	15
5-17-2004	Wild	75	87	12
5-17-2004	Wild	57	78	21
5-17-2004	Wild	53	55	2
5-17-2004	Hatchery	47	57	10
5-17-2004	Hatchery	63	62	-1
5-17-2004	Hatchery	50	54	4
5-17-2004	Hatchery	63	69	6

Table 7. Mean survival for naïve and experienced fry.

	Naïve	Experienced	Survival difference (exp. – naïve)
2003 Wild	53.83	61.17	7.3
2003 Hatchery	54.33	75	20.7
2004 Wild	59.00	71.50	12.5
2004 Hatchery	55.75	60.50	4.8
Total Wild	55.9	65.3	9.4
Total Hatchery	54.9	69.2	14.3

Discussion

Although we found no difference in survival between the hatchery and wild fish during 2003 ($P = 0.051$) and 2004 ($P = 0.122$) (Table 5), by combining the results of the 2003 and 2004 data, the wild fish survival is significantly higher than the hatchery fish survival ($P = 0.016$). This is likely a mechanism of increasing the degrees of freedom, thereby making the test more powerful in detecting small differences. We speculate that it is possible to detect differences in survival between the hatchery and wild origins in some years and not to detect differences in other years due to fluctuations in run size from year to year. For example, assume that the numbers of adults used for broodstock at the CESRF were to remain relatively constant and the numbers of adults spawning naturally fluctuated by several orders of magnitude. It is theoretically possible for the supplementation (wild) line to express varying degrees of predation vulnerability from year to year due to density dependent selection pressures in the river environment. Offspring from an abundant run of adults may experience less pressure per capita from an essentially constant level of predation, thus more juveniles could survive that do not express traits that are advantageous to avoid predation. If these fish survive to spawn, they could produce more offspring that inherit those traits, which may limit our ability to detect a difference between the two origins. The opposite would be true for the offspring of a weaker run of adults and there could be greater differences in the two origins that we would be able to detect. Thus, in some years the per capita predation selection could be very similar in natural and hatchery environments (no selection) and in other years the selection differential could be large.

Because we used prey fish that were treated identically, any differences we observe should be due to genetic differences and not abnormal behavior that is learned in the hatchery environment. This means that any differences that we find would be expressed in the natural environment. However, because our experiments were conducted in an artificial environment, we do not know how differences will be manifested in the natural environment. For example, in years of low predation pressure, no differences in survival may occur. Since these returning hatchery-reared offspring of wild fish are expected to spawn and produce viable fry, any deficiencies expressed will limit the success of supplementation.

It is important to know what the mechanisms are that are causing a difference in survival between the two origins. The fish may exhibit different behaviors that make them more or less attractive or available to predators (Johnsson and Abrahams 1991; Healey and Reinhardt 1995) or some fish may not be as physically capable to escape a predator attempting to capture them. Even though domesticated hatchery fish may exhibit lower survival in the natural environment due to predation, some could argue that other genetic changes such as earlier emergence and faster growth could make up for their increased vulnerability to predation by giving them a size advantage over wild fish. Over the size ranges of prey fish we tested, we could not reject the hypothesis that certain sizes of prey were eaten preferentially over others. The average length gain of the fry during the predator trials was 0.75 mm for the five-day period, which is slightly higher than the mean growth during the dominance experiments in 2003 and 2004 (0.41 mm; chapter 2 of this report). The 0.34 mm difference was likely due to some size selective predation that was not statistically detectable. We found a higher incidence of significantly larger survivors at the end of the trials during 2004 relative to 2003 but are unable to conclude this was due to size selective predation because the fry during 2004 were on a faster growth regimen than 2003, which may have continued during the net pen trials. The faster growth regime during 2004 also resulted in larger mean lengths of fry used in the experimental trials (2003 = 44.2 mm FL, 2004 = 46.6 mm FL). This could have resulted in greater size selectivity by the predators during 2004 due to higher numbers of larger, quicker fry and the gape limitations of the predators, although there was no relationship between fry size at stocking and the percentage of trials that were significantly different in size between stocking and removal. It would be advantageous to run a week of predation trials with one group of prey significantly smaller in size than the other in order to measure the effects of size on predation vulnerability more directly.

The results from the naïve versus experienced trials indicate that even if there is a 2% reduction in survival of the hatchery fish, they would still have the capacity to more than make up for that difference through experience with predators (Table 7). During the two years of naïve versus experienced trials, the experienced fry had a minimum of a 4.8% improvement in survival over their naïve cohorts. Whether this survival gain through experience with predators is due to culling of less fit individuals or a learning mechanism is unknown. We were unable to observe any adverse behaviors in the fry that were consumed during some observational trials in 2004.

During 2004, we used two rainbow trout and two torrent sculpins per net pen as opposed to three of each in order to keep consumption below 50%. We believe that once the most vulnerable fry are eaten, predators will concentrate on the less vulnerable prey. This would result in the equalization of relative predation vulnerability and a dependency situation. For the 28 trials during 2003, the mean consumption was 41% (range, 18-61%) of all fish per pen. If we assume that all predators in a net pen were eating an equal number of fry, then the reduction of one predator per species should still give us an average consumption of 27% (range, 12-41%). Using fewer predators during 2004, the mean consumption was 24% (range, 5-69%). This made it much easier to get enough new predators for trials and we believe that this still allows us to obtain meaningful results.

The combined data of 2003 and 2004 yielded a significant survival difference of only 2.15% on average. Beginning in 2005, we will have a wild control line of fry that have never been exposed to the hatchery environment. These fish are the offspring of wild adults collected on the spawning grounds of the Little Naches River, which does not contain a hatchery. These fry will be tested with the supplementation line and the hatchery control line and provide a baseline of predator avoidance ability. If the difference in survival between the wild control line and the supplementation line remains at this magnitude or less, and the hatchery control line survival decreases over time compared to the other two lines of fish, then supplementation should be viewed as a success in terms of producing fish that are able to perform as well as naturally produced fish when encountering piscine predators.

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Chapter 2

The Effects of Domestication on Competitive Dominance of Juvenile Spring Chinook Salmon

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Abstract

We tested the null hypothesis that competitive dominance among chinook salmon would not be affected by domestication selection after one generation of hatchery culture. Fish that were used in the experiments were offspring of naturally produced spring chinook salmon (wild) and offspring of spring chinook salmon that spent one generation under hatchery culture (hatchery). Both fish had grandparents that were naturally produced in the upper Yakima River. Fish were mated and reared as part of a common garden experiment. We tested two types of competitive dominance, contest and scramble. Dyadic challenges of size-matched juvenile fish were conducted after a six day acclimation in 80, 113.4-liter aquaria. In the contest trials, we created one highly profitable location in the aquaria. This location provided instream cover, food, and water velocity. Dominance was assigned to the fish that ate the most pellets within the water column, was in the preferred habitat the most, and initiated and dominated the most behavioral contests. In the scramble trials, the cover was removed from the tanks and food was introduced in unpredictable locations upon the water surface. Dominance was assigned to the fish that ate the most pellets. Wild fish dominated 4% more contests than hatchery fish when data from 2003 and 2004 were combined ($P=0.050$), but tests from individual years were not significantly different ($P>0.05$). Dominance was not significantly different in any of the scramble competition trials ($P>0.05$). Wild fish generally initiated more agonistic interactions than hatchery fish in both contest and scramble trials. There were no differences in the frequency of different types of agonistic interactions that were used by hatchery and wild fish, except that wild fish used chasing behaviors more than hatchery fish in 2003 contest trials ($P<0.05$). We also found that dominant fish grew more than subordinate fish in both contest and scramble trials ($P<0.05$). Our results suggest that offspring of first generation hatchery fish that spawn in the Yakima River will be slightly less dominant in contest competition than wild fish if the timing and size of emergence, and growth rates are similar. These data should be considered preliminary until published in a peer-reviewed journal.

Introduction

Despite our best efforts, raising fish in hatcheries can cause unintended behavioral changes in salmonids due to domestication selection. Domestication selection is defined by Busack and Currens (1995) as "changes in quantity, variety, or combination of alleles within a captive population or between a captive population and its source population in the wild as a result of selection in an artificial environment." Selection in artificial environments could be due to intentional or artificial selection, biased sampling during some stage of culture, or unintentional selection (Busack and Currens 1995). The goal of supplementation or conservation hatcheries is to produce fish that will integrate into natural populations. Conservation hatcheries attempt to minimize intentional or biased sampling so that the hatchery fish are similar to naturally produced fish. However, the selective pressures in hatcheries are dramatically different than in the wild, which can result in genetic differences between hatchery and wild fish. The selective pressures may be particularly prominent during the freshwater rearing stage where substantial mortality of wild fish occurs (Groot and Margolis 1991).

During freshwater rearing, salmonids in hatcheries and rivers use very different methods to acquire food. River environments are very heterogenous (e.g., patchy) with respect to food and habitat quality. Salmonids rearing in streams primarily feed on drifting invertebrates as they maintain energetically profitable stream locations (Fausch 1984). Dominant fish secure the most food and grow the fastest (Metcalfe 1986). These fish use a variety of agonistic interactions, such as nips, butts, chases, and threats to defend territories that have predictably high levels of food (Chapman 1962; Grant and Kramer 1990; McMichael et al. 1999). This type of interference interaction is referred to as contest or interference competition (Birch 1957). In contrast, salmonids in hatchery raceways live in homogenous environments where positions are equally viable. Fish in hatcheries frequently use shoaling or schooling behaviors and acquire food from the water surface. Thus, agonistic interactions prior to food interactions is wasted energy but with little immediate consequences in hatchery environments where food is plentiful and predators absent. Fish that are in the right place at the right time and that swim rapidly towards the food are the most successful. This type of interaction is referred to as scramble or exploitative competition (Birch 1957).

Domestication selection has been shown to alter the aggressiveness and dominance of hatchery fish. Domestication has been implicated as causing either an increase or decrease in aggressive and schooling behavior in fish (Ruzzante 1994). Berejikian et al. (1996) found that offspring of wild steelhead trout were more aggressive and dominant (87.5%) than size matched offspring of parents that had been in hatchery culture for 4 to 7 generations. However, when hatchery fry had a 3.0-4.5% size advantage, they dominated wild fish in 68% of encounters. Swain and Riddell (1990) found that domesticated coho were more aggressive than those of natural origin from nearby streams. Hatchery reared chinook salmon dominated smaller wild chinook salmon and altered wild fish behavior in an artificial stream channel (Peery and Bjornn 1996). Petersson and Jarvi (2000) suggested that both contest and scramble competition affected the growth of brown trout, *Salmo trutta*, parr of natural and sea-ranched origins. Farrell (2003) found that wild spring chinook salmon from the Yakima Basin were competitively dominant to descendents of first generation local origin hatchery fish in contest competition trials during 2002.

Dominance among salmonids has been demonstrated to be most consistently associated with fish size (Abbott et al. 1995, Berejikian et al. 1996, McMichael et al. 1999), but prior residence, prior winning experience, genetics, aggressiveness, and hatchery rearing also influence dominance (Huntingford et al. 1990, Berejikian et al. 1996, Rhodes and Quinn 1998). Differences in aggression are related to metabolic rate (Metcalfe et al. 1995), genetics (Taylor and Larkin 1986; Rosenau and McPhail 1987), and rearing experience (Berejikian et al. 1996; Rhodes and Quinn 1998). Coloration may also influence dominance. Dominant salmonids are generally lighter colored than subordinates (Rosenau and McPhail 1987; Berejikian et al. 1999; Weber and Fausch 2003). A fish's gender may also influence dominance, but this has received little attention in the literature. Johnsson and Akerman (1998) reported no differences in aggression between male and female juvenile rainbow trout.

The goals of this study were to determine if there are differences in dominance between offspring of wild and first generation hatchery upper Yakima Basin spring chinook salmon under 1) contest and 2) scramble competition, and 3) determine if differences in dominance are related to differences in aggression, color, and gender. In addition, we observed that hatchery fish grew faster in scramble competition trials in 2003 than wild fish even when they were not dominant. In light of this finding, we also designed a study to determine if there were differences in growth rates between hatchery and wild fish when no competition existed. If domestication does not occur, we would expect offspring of hatchery and wild fish to have equivalent levels of aggression and dominance. If domestication does occur, we would expect offspring of hatchery fish to be the dominant in scramble competition, and offspring of wild fish to be dominant in contest competition. Alternatively, the more aggressive fish may be the most dominant in both types of competition. In addition, we would expect that these differences would be accentuated with each successive generation.

Methods

Fish used in this experiment were either juvenile offspring of wild spring chinook salmon (wild) or offspring of fish that spent one generation in the hatchery (hatchery). The fish that spent one generation in the hatchery were offspring of wild spring chinook salmon that were collected at Roza Dam as part of the Yakima Fisheries Project Supplementation Program. The only difference between the two types of fish was that one type spent one generation in the hatchery.

The fish that spent one generation in the hatchery were treated using state-of-the-art fish culture practices. Hatchery and wild fish are collected in proportion to their abundance and timing at Roza Dam. Adult fish that were taken to the hatchery were spawned, eggs incubated, and juveniles reared in one of two types of raceways under similar densities (e.g., approximately 40,000 fish/raceway). The two types of rearing environments differed in their degree of "naturalness". The "optimal conventional treatment" (OCT) is a combination of the conventional factors that have been demonstrated to produce good results from other hatcheries. This includes low rearing density, optimal flow conditions, and desirable food distributions. The second of the two treatments, "semi-natural treatment" (SNT), uses the same strategies as the OCT but adds some factors that are present in natural streams. These factors include overhead cover (floating mats), instream cover (christmas trees), natural coloration (painted raceways), and underwater feeding.

Fish that were used for this experiment were collected at Roza Dam, held in ponds, spawned, incubated, and reared at the Cle Elum Supplementation and Research Facility. Hatchery and wild fish were collected in proportion to the run throughout the season at Roza Dam. Naturally produced fish were spawned with naturally produced fish to produce "wild" fish, and hatchery fish were spawned with hatchery fish to produce "hatchery" fish. A factorial mating scheme was used to spawn both groups of fish. After spawning, fertilized eggs were disinfected and placed into isolettes within incubation trays. Dead eggs and monstrosities were removed. The fish used for experimentation were taken from isolettes that were used for experimental crosses to gather data on other aspects of the domestication work (see Knudsen et al. 2003 for more detail on isolettes and crosses). We selected approximately 12,000 fish (2003) and 8,000 fish (2004) of each origin, hatchery by hatchery (H x H) and wild by wild (W x W). Isolettes were selected in a way that ensured nearly all adult broodstock used for the experimental isolette crosses were represented in our sample at least once (33 (2003), 18 (2004) wild females, 25 (2003), 18 (2004) wild males, 32 (2003), 20 (2004) hatchery females and 15 (2003), 20 (2004) hatchery males; 58 (2003), 54 (2004) wild families and 59 (2003), 58 (2004) hatchery families). All surviving fish in each selected isolette were used, even if there were very few. This ensured that our sample of experimental fish represented the true reproductive effort expressed by each cross. These fish were transferred into two identical 1701-liter polyethylene conical-bottomed circular tanks on April 17, 2003 and April 19, 2004 and fed starter feed until large enough to feed on Bio-moist pellets.

Experiments were conducted in 80, 113.4 liter glass aquaria (91.4 cm (36") long, 30.5 cm (12") wide, 40.6 cm (16") deep inside dimensions) at the Cle Elum Hatchery. Two types of dominance experiments and one type of growth trial were conducted. The first experiment was designed to assess dominance under contest competition and the second experiment was designed to assess dominance under scramble competition. In both experiments, fish were anesthetized with MS-222, fish length (fork length; mm FL) and weight (mg) were recorded, size matched (fork length), and the adipose fin was either completely excised or slit so that the fin remained intact. This allowed us to identify the origin of each fish during observations and the slit fin was intended to put the "unmarked" fish under similar handling procedures as the marked fish. Marks were alternated between aquaria and origin to eliminate any behavioral difference due to marking stress. Fish were allowed to recover from anesthetization and then stocked into aquaria. Both fish were introduced at the same time to prevent any prior residence advantage. Observations were done on the seventh day in the test arena. Fish were fed a total of 10 pellets during each acclimation day, except for the first day stocked and the sixth day when fish were not fed. Fish were fed through a feeding tube in contest experiments and from the surface in scramble experiments. In the single fish growth trials, individual fish were introduced into aquaria set up like the contest trials and fed the same way as in contest trials. Fin clips were alternated between tanks and origins in growth trials as well. Pellets consumed during the acclimation week and during the trial were recorded.

Contest competition

The arenas were configured to provide one highly preferred location that was close to an underwater food source, provided cover, and had desirable water velocities. A blind was constructed out of camouflage netting to prevent fish from seeing the observer. One hatchery and one wild spring chinook salmon was placed in each chamber. Fish were acclimated for six days in each of the arenas. This time length was determined by comparing behavioral responses and dominance from pairs of fish that were held for different lengths of time during previous experiments (Pearsons et al. 2001). After six days the behavioral responses and dominance did not generally change. After acclimation, food acquisition, agonistic interactions, and habitat location was measured on day seven.

Food pellets, ground into a slurry, were introduced through a tube with running water to alert fish that food was available. Once both fish had keyed into the food source, then one food pellet was added at approximately one-minute intervals. During 2003, we increased the size of the pellets that were fed to the fish as fish length increased. During 2004, we used small pellets throughout the duration of the experiment to ensure that fish would not become satiated and cease interacting during the contests. The number of food items acquired by each fish was recorded. Agonistic interactions were recorded throughout the duration of the trial. We recorded which fish initiated an interaction and whether they dominated. Dominance was assigned to the fish that defended a position or removed another fish from a preferred position. Type of interaction was recorded as: nip (contact with mouth open), butt (contact with mouth closed), chase (no contact, swimming after another fish for at least 1 body length), threat (no contact; for example fin flares, opercle flares, swimming side by side), crowd (no clear threat but physical presence moved the other fish away)

The location of each fish was recorded once every minute. The location was expressed as which fish, if any, was in the most desirable spot. The most desirable spot was defined as the fish that was closest to the source of food, flow, and cover. This was generally in the middle of the tank, from 2.5 to 25 centimeters off the bottom, and from the end of the pipe to 30 centimeters down flow of the pipe. If both fish were in this zone, then the fish closest to the pipe was assessed to be dominant. Total observation time for each arena was approximately 20-25 minutes (not including slurry time). Dominance was attributed to the fish that won at least two of three categories; acquired the most food, initiated the most behavioral contests, and occupied the preferred location the most. If fish did not consume at least 10 pellets together or if fish did not interact with each other, then they were not included in the analysis. Relative coloration was also recorded. This was expressed as which fish was darker than the other (background body coloration). Fish size, growth, gender, and rearing history were examined to determine how they influence dominance.

Scramble competition

Methods for scramble competition were the same as those for contest competition except for the following differences. The configuration of arenas was the same except that the cover was removed. In addition, food was introduced onto the surface of the water. Food was tossed into one of five locations every minute. The locations were the four corners and the center of the aquaria. These locations were rotated such that no position in the tank was superior to another. Dominance was assigned to the fish that ate the most pellets.

Single fish growth trials

Methods used for single growth trials were the same as those for contest competition except that only one fish was introduced into each aquaria, so no interactions were recorded. Pellets consumed during the acclimation phase and during the trials (up to 20 pellets) were recorded. Lengths and weights were taken before and after to assess relative growth. Differences were assessed using student's t-tests.

Analysis

Paired comparisons of dominance and agonism were made for each replicate using either a two-tailed Wilcoxon matched pairs or paired sign test. A statistically significant test indicated that dominance was influenced by hatchery rearing. Paired comparisons of growth and interaction rate were compared using a two-tailed paired student's t-test. Differences were considered significant if P values were less than or equal to 0.05. Statistical tests were performed using the software program Statistica (StatSoft, Inc., 2001) and student's t-tests in Microsoft Excel.

Results

Contest competition

Wild fish were 4% more dominant than hatchery fish when 2003 and 2004 data were combined (Table 1). However, overall dominance was not significantly different between hatchery and wild fish during each individual year. Wild fish initiated and dominated significantly more agonistic interactions than hatchery fish during 2003 and initiated more interactions when both years were combined (Table 1). Food acquisition and habitat occupation were not significantly different between hatchery and wild fish in contest competition trials (Table 1). Dominance was assessed in 229 out of 256 (2003) and 276 out of 307 (2004) trials. Twenty-seven trials in 2003 and thirty-one trials in 2004 had to be eliminated because one of the fish escaped, died, or they did not meet the criteria for an acceptable trial (e.g., abnormal behavior or no clear dominant). All fish were size matched to the nearest mm FL except in 2003, where there were 15 trials where the fish were only size matched to within 1 mm. Frequency of interaction types used by hatchery and wild fish were not significantly different, except that wild fish used chases significantly more in 2003 than hatchery fish (Table 2).

There was no difference in the growth (mm) of hatchery and wild fish. Both origins lost weight on average in 2004, with hatchery losing significantly more (Table 3). Dominant fish grew significantly more than subordinate fish (Table 3) in both lengths and weights. In 2004, practice pellets eaten were recorded during the acclimation phase. There was no significant difference in pellets consumed or growth per pellet for either origin (Table 4). The dominant fish ate the most pellets 88% of the time during both acclimation and trials combined. The darker colored fish were significantly more dominant than lighter fish, regardless of origin (Table 5) in 2003 and when combined, but not significantly in 2004. There was no difference in dominance based on gender (Table 6) and there was no difference in growth of male or female fish ($P>0.05$).

Table 1. Food acquisition, habitat occupation, agonism initiation, agonism dominance and overall dominance in contest competition trials. P values are from two tailed matched pairs Wilcoxon tests. The test for total dominance was a matched comparison of the sums of percentages.

Origin	n	% Food	% Habitat	% Initiations	% Dominated Interactions	% Total Dominance
2003 Wild		54%	54%	55%	56%	54%
2003 Hatchery		46%	46%	45%	44%	46%
2003 P	229	0.103	0.249	0.036	0.049	0.081
2004 Wild		52%	52%	52%	51%	51%
2004 Hatchery		48%	48%	48%	49%	49%
2004 P	276	0.411	0.517	0.435	0.630	0.302
Total Wild		53%	53%	53%	53%	52%
Total Hatchery		47%	47%	47%	47%	48%
Total P	505	0.083	0.203	0.042	0.094	0.050

Table 2. Frequencies of interaction types initiated by hatchery and wild fish in contest competition trials. Number of total interactions and interaction rate (average interactions per minute for all tanks) are also presented. P-values for interaction types are from two-tailed paired Wilcoxon tests and for interaction rate, a paired t-test.

Origin	Crowd	Threat	Chase	Butt	Nip	Total Interactions	Interaction Rate (+/- SD)
2003 Wild	5%	48%	22%	13%	12%	3275	0.63 (0.62)
2003 Hatchery	5%	51%	18%	14%	11%	2910	0.57 (0.66)
2003 P	0.896	0.377	0.028	0.556	0.772		0.380
2004 Wild	2%	54%	18%	11%	15%	4589	0.70 (0.73)
2004 Hatchery	2%	55%	19%	10%	14%	4335	0.65 (0.71)
2004 P	0.729	0.987	0.678	0.952	0.537		0.466
Total Wild	3%	52%	20%	12%	14%	7865	0.67 (0.68)
Total Hatchery	4%	54%	18%	12%	13%	7245	0.62 (0.69)
Total P	0.993	0.568	0.250	0.754	0.520		0.222

Table 3. Growth and frequency of dominance of fastest growing wild and hatchery fish in contest competition trials. Percent dominance is the percentage of trials that wild or hatchery fish was dominant when it also grew the most (length or weight). P-values are for paired t-tests (growth) and paired sign tests (% dominance) for fish regardless of origin.

Origin	n	Average Growth mm (S. D.) Length	Average Growth Mg (S.D.) Weight	% Dominant when Grew the Most (Length)	% Dominant when Grew the Most (Weight)
2003 Wild		0.44 (1.24)	94.70 (279.32)	75%	80%
2003 Hatchery		0.59 (1.33)	57.72 (290.37)	82%	80%
2003 P	227	0.133	0.223	<<0.001	<<0.001
2004 Wild		0.31 (0.96)	-52.55 (216.57)	58%	87%
2004 Hatchery		0.34 (0.93)	-102.53 (256.63)	74%	84%
2004 P	276	0.698	0.026	<<0.001	<<0.001
Total Wild		0.37 (1.09)	14.22 (257.43)	72%	84%
Total Hatchery		0.46 (1.14)	-30.21 (283.56)	78%	82%
Total P	505	0.156	0.017	<<0.001	<<0.001

Table 4. Average growth based on total pellets consumed throughout training week (5 days) and trial. Length measured in mm and weight in mg. P values are based on Wilcoxon paired sample tests.

	Average Total Pellets Eaten	Average Length gain per pellet eaten	Average weight gain per pellet eaten
2004 Wild	22.4	0.02	-16.08
2004 Hatchery	21.1	0.01	-30.78
2004 P	0.382	0.760	0.322

Table 5. Dominance of lighter and darker colored fish in contest competition trials (some had no color assignment or classified as equally dark). P-value is from a paired sign test evaluating if there was a difference between fish of different color and dominance.

	Lighter and Dominant	Darker and Dominant	Total
2003 Total	32 (18 H, 14 W)	103 (43 H, 60 W)	135
2003 P			<<<0.001
2004 Total	77 (28 H, 49 W)	105 (53 H, 52 W)	182
2004 P			0.055
Total	109 (46 H, 63 W)	208 (96 H, 112 W)	317
Total P			<<0.001

Table 6. Dominance of each origin for contest competition based on gender. P value is based on a paired sign test.

	Dominant Fish		
	Hatchery	Wild	Total
2004 Female	54	48	102
2004 Male	39	60	99
2004 Total	93	108	201
2004 P	0.147	0.147	0.888

Scramble competition

Total dominance, food acquisition, and agonism dominance were not significantly different between hatchery and wild fish in scramble competition trials (Table 7). When 2003 and 2004 were combined, wild fish initiated significantly more interactions than hatchery fish (Table 7). However, the frequency of interactions that were initiated were not significantly different during the individual years. Dominance was assessed in 97 out of 112 trials (2003) and 266 out of 296 trials in 2004. Fifteen trials (2003) and thirty trials (2004) had to be eliminated because one of the fish escaped or they did not meet the criteria for an acceptable trial. In 2003, the fish were the same length in all but 21 of the trials, and of these 21 trials they were 1 mm FL different. All of the fish were the same size at stocking during 2004. The types of interactions and interaction rate that hatchery and wild fish initiated were not significantly different (Tables 8). In 2003, the growth of hatchery fish was significantly greater than wild fish for both length and weight. In all cases, the dominant fish was the one that grew the most, regardless of origin. In 2004, neither origin grew significantly more than the other and both origins lost weight on average. (Table 9). When all data were combined, wild fish lost significantly more weight than hatchery fish (Table 9). Pellets eaten during the five-day acclimation period were recorded in 2004. There was not a significant difference in total pellets consumed (during acclimation and trial periods combined) between origins or between length gain per pellet; but hatchery fish lost significantly more weight per pellet consumed than wild fish (Table 10). The dominant fish ate the most pellets 85% of the time during both acclimation and trials combined. There were more lighter colored fish that were dominant than darker fish for each year, but the difference was not significant until the data were combined for the two years (Table 11). There was no significant difference between gender and the dominant fish (Table 12).

Table 7. Dominance, food acquisition, agonism initiation, and agonism dominance in scramble competition trials. Mixed scramble competition total dominance determined by % food eaten only. Wilcoxon matched pairs test were used to produce P values.

Origin	n=	% Food	% Initiations	% Dominated Interactions	% Total Dominance
2003 Wild		48%	57%	54%	45%
2003 Hatchery		52%	43%	46%	47%
					7% Equal
2003 P	97	0.568	0.056	0.445	0.855
2004 Wild		51%	53%	55%	50%
2004 Hatchery		49%	47%	45%	46%
					4% Equal
2004 P	266	0.453	0.124	0.136	0.616
Total Wild		51%	54%	54%	48%
Total Hatchery		49%	46%	46%	47%
					5% Equal
Total P	363	0.741	0.019	0.098	0.747

Table 8. Frequencies of interactions initiated by hatchery and wild fish in scramble competition trials. Total interactions and interaction rate (average interactions per minute for all tanks) are also presented. Wilcoxon matched pairs tests were used for interaction types and a paired t-test was used for interaction rate.

Origin	Crowd	Threat	Chase	Butt	Nip	Total Interactions	Interaction Rate (+/- SD)
2003 Wild	12%	46%	19%	8%	14%	1239	0.60 (0.65)
2003 Hatchery	6%	48%	18%	13%	15%	944	0.46 (0.66)
2003 P	0.451	0.793	0.966	0.126	0.351		0.203
2004 Wild	1%	50%	20%	9%	19%	4983	0.82 (0.83)
2004 Hatchery	1%	55%	17%	9%	18%	4773	0.78 (0.91)
2004 P	0.954	0.325	0.299	0.967	0.481		0.323
Total Wild	4%	49%	20%	9%	18%	6222	0.76 (0.79)
Total Hatchery	2%	53%	17%	10%	18%	5717	0.69 (0.86)
Total P	0.586	0.391	0.342	0.431	0.325		0.119

Table 9. Growth and frequency of dominance of fastest growing wild and hatchery fish in scramble competition trials. % dominance is the percentage of trials that wild or hatchery fish was dominant when it also grew the most (length or weight). P-values are for paired t-tests (growth) and paired sign tests (% dominance) for fish regardless of origin.

Origin	Average Growth mm (S. D.) Length	Average Growth mg (S.D.) Weight	% Dominant when Grew the Most (Length)	% Dominant when Grew the Most (Weight)
2003 Wild	0.37 (0.86)	48.85 (513.12)	39%	48%
2003 Hatchery	0.77 (0.80)	285.35 (456.74)	80%	78%
2003 P	0.0008	0.0009	0.049	0.015
2004 Wild	0.24 (1.27)	-149.38 (545.81)	68%	80%
2004 Hatchery	0.27 (1.11)	-131.06 (294.81)	66%	79%
2004 P	0.647	0.615	<<0.001	<<0.001
Total Wild	0.27 (1.18)	-96.41 (543.71)	61%	72%
Total Hatchery	0.41 (1.06)	-19.79 (391.14)	70%	79%
Total P	0.480	0.020	<<0.001	<<0.001

Table 10. Average growth based on total pellets consumed throughout training week and trial. P values are based on Wilcoxon paired sample tests.

	Average total pellets eaten	Average length gain per pellet eaten	Average weight gain per pellet eaten
2004 Wild	22.58	0.018	-22.45
2004 Hatchery	20.44	-0.002	-37.30
2004 P	0.097	0.866	0.030

Table 11. Dominance of lighter colored fish in scramble competition trials. Trials in which there was equal dominance or where color difference could not be discerned were not analyzed. A sign test was used to test for differences.

	Lighter and Dominant	Darker and Dominant	Total
2003 Total	24 (7 H, 17 W)	12 (8 H, 4 W)	36
2003 P			0.067
2004 Total	99 (42 H, 57 W)	77 (43 H, 34 W)	176
2004 P			0.113
Total	123 (49 H, 74 W)	89 (51 H, 38 W)	212
Total P			0.023

Table 12. Dominance of each origin for scramble competition based on gender. P value is based on a paired sign test.

	Dominant Fish			
	Hatchery	Wild	Equal	Total
2004 Female	46	41	3	90
2004 Male	37	61	3	101
2004 Total	83	102	6	191
2004 P	0.380	0.060		0.462

Single Fish Growth Trials

There was no significant difference in the average growth between origins or the average growth per pellet consumed. Wild fish consumed significantly more pellets throughout the acclimation and trial periods than did hatchery fish (Table 13). The water temperature in the tanks during the trials was also not significantly different.

Table 13. Total average growth and growth per pellet eaten for single trials.

	n=	T °C	Average Length Growth	Average Weight Growth	Average Total Pellets Eaten	Average Length gain per pellet eaten	Average Weight gain per pellet eaten
2004 Wild	125	14.09	0.64	116.67	40.43	0.02	2.62
2004 Hatchery	125	14.04	0.55	118.53	37.47	0.02	2.56
2004 P		0.747	0.613	0.954	0.034	0.951	0.952

Discussion

One generation of hatchery exposure decreased the competitive dominance of hatchery fish by 4% in contest trials when 2003 and 2004 data were combined, but comparisons were not significantly different when the data were analyzed for each individual year. It is possible that detection of such a small difference was only possible with a very large number of replicates. Combining the two years of data provided a very high number of replicates (n=505). Although, neither year was significantly different, wild fish were 8% and 2% more dominant in 2003 and 2004, respectively. If higher numbers of replicates were available during each individual year, then significant differences may have been detected. This study demonstrates the large number of replicates that are necessary to detect small domestication effects in dominance. If this study had been conducted during a single year, as most studies of this nature have been, then a different conclusion would have been made. However, a similar study that used similar fish and facilities in the Yakima River but with lower numbers of replicates during 2002 also found that wild fish were more dominant than hatchery fish in contest competition trials (Farrell 2003). Thus, it is possible that differences in competitive dominance may vary across years.

It is likely that wild fish were more dominant in contest trials because they were more aggressive. Wild fish initiated more agonistic interactions than hatchery fish in both contest and scramble trials. Aggression in scramble trials provided no obvious benefit to wild fish, because no places in the tank were any better than others. In contrast to our study, juvenile coho salmon reared in hatcheries have been documented to be more aggressive than wild fish (Swain and Riddell 1990; Berejikian et al. 1999). Furthermore, Einum and Fleming's 2001 meta-analysis of aggression revealed that hatchery fish were more aggressive than wild fish.

Our results suggest that offspring of first generation hatchery fish that spawn in the Yakima River will be slightly less dominant than wild fish if the timing and size of emergence, and growth rates are similar. However, if emergence time, size at emergence, or growth rates diverges between offspring of hatchery and wild parents, then biological factors could influence dominance patterns. In the 2003 scramble trials, hatchery fish grew more than wild fish even though dominance was not significantly different. This suggested that hatchery fish had a greater capacity to grow than wild fish. However, no differences in growth were detected when fish were tested individually during 2004. Farrell 2003 found that hatchery fish grew faster than the wild fish even when the amount of food delivered was the same. This resulted in hatchery fish being larger than wild fish. Berejikian et al. 1996 found that an approximate size advantage of 3.0-4.5% could provide hatchery steelhead fry a dominance advantage even when size matched fish were competitively inferior to wild fish. It is likely that divergences in phenotypic or genotypic characteristics that affect size differences in offspring of hatchery and wild fish has the potential to influence dominance relationships more than genetic differences in dominance (e.g., differences in dominance of size matched fish as tested in this experiment). Therefore, it is important to monitor factors that influence size differences of juvenile hatchery and wild fish.

For hatcheries that use wild endemic broodstock and best hatchery practices, differences in aggressiveness and dominance between hatchery and wild fish may be more strongly influenced by hatchery rearing and relative size than the genetic effects of behavioral domestication. In this study, we found that wild fish were slightly more dominant than hatchery fish. In another study we found that spring chinook smolts reared in the hatchery dominated salmon smolts that were reared in the Yakima River. Larger fish generally dominated smaller fish, but the size difference didn't have to be as large for hatchery fish to dominate as wild fish (Pearsons et al. Unpublished data). In short, hatchery fish were dominant over wild fish in contest competition trials unless wild fish were sufficiently larger than hatchery fish. In a study of coho salmon, Rhodes and Quinn (1998) reported similar findings. In short, dominance may be influenced more by rearing experience than by genetic changes that occur over a single generation of hatchery culture.

Fish gained weight in 2003, but lost weight in 2004 during contest and scramble competition trials. The weight loss in 2004 was likely due to feeding the fish the same weight of food throughout the duration of the experiment. At the same time, the size of fish used in the experiment increased and the water temperature increased. Both of these factors contribute towards an increased metabolic demand. In contrast, in 2003 we increased the pellet size fed to the fish as the metabolic demand increased.

Darker fish were more dominant in our contest trials and less dominant in scramble trials. Coloration is thought to signal fish about level of dominance (Weber and Fausch 2003). It has been reported that dominant fish are lighter in color than subordinate fish (Rosenau and McPhail 1987; Berejikian et al. 1999). Our scramble trials were consistent with the prevailing literature, but our contest trials were contrary. Contrast between coloration of the body and parr marks or fins may be a better indicator of dominance signaling than background body coloration (Weber and Fausch 2003). We intend to record both color classifications during 2005 trials.

We did not detect any difference in dominance associated with fish gender. Johnsson and Akerman 1998 found that multi-generation farm strain rainbow trout males were more aggressive and dominated more behavioral contests with females.

Our study and Farrell 2003 are somewhat unique in that the hatchery and wild population were founded from the same source, the hatchery population was in the hatchery for only a single generation, and that hatchery protocols were directed at producing fish that minimized divergence from wild fish. Other studies have demonstrated differences in aggression or dominance, but these studies have used fish that have come from different sources, have been under hatchery culture for many generations, and/or have come from hatcheries whose protocols are not intended to produce fish that reproduce well in natural systems (Riddell and Swain 1991, Berejikian et al. 1996).

Domestication was detected within the first generation of hatchery culture, even though extreme measures have been used to minimize domestication. The CESRF uses some of the best facilities and techniques to minimize domestication. In addition to the difference in dominance that we observed in this study, Chapter 1 documents that offspring of hatchery parents were eaten at a slightly greater rate than offspring of wild parents. The fish used in these predation experiments were from the same matings and same rearing procedures used in this study. Greater amounts of domestication can be expected from hatchery programs that are not as risk averse as CESRF.

This is the second year of a long-term evaluation of the effects of hatchery domestication on dominance and aggression of spring chinook salmon. Results may differ with increasing numbers of generations of hatchery culture. In 2005, we will replicate this study, but also add trials that will assess dominance of offspring from our wild control line that were collected from the Naches Basin. If time is available, we will also test whether dominance relationships observed in aquaria are the same as in the field. This might be accomplished by taking known dominant and subordinate fish from aquaria and placing them in the experimental spawning channel or in an enclosure in the field. Observations would then be made using snorkeling and the dominance of the fish assessed using methods described in this study.

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