ESCAPEMENT, OCEAN HARVEST AND STRAYING OF HATCHERY AND NATURALLY REARED CHINOOK SALMON IN THE MOKELUMNE RIVER, CALIFORNIA

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Abstract. – We examined the potential effects of various hatchery release strategies practiced at the Mokelumne River Fish Hatchery (MRFH) on natural populations of fall-run chinook salmon, *Oncorhynchus tshawytscha*, in the lower Mokelumne River. We compared escapement, ocean harvest and straying rates of natural and hatchery reared fish by evaluating adult coded wire tag recovery data. . Approximately 4,005,811 juveniles of various brood stock reared at the MRFH were coded wire tagged (tagged), adipose fin-clipped (marked) and released at various sizes and locations from 1991 through 2000. Between 1993 and 2000, approximately 231,207 naturally reared fish captured in the lower Mokelumne River were tagged, marked and released at the capture site. The frequency of ocean and inland recoveries was significantly different for hatchery (combined stock origin, release size and release location) and naturally reared fish with a greater proportion of hatchery fish recovered in the ocean harvest than naturally reared fish. However, a significantly greater proportion of naturally reared fish were recovered in the ocean harvest than Mokelumne River origin hatchery stock released as smolts in the Mokelumne River. We also found significant differences between inland and ocean recoveries of hatchery fish based on stock, size at release and release location, with greater proportions of out-of-basin stock (Feather and American river), post-smolt releases and releases in the Bay-Delta recovered in the ocean harvest. A significantly greater proportion of hatchery fish strayed (14.8% to 71.3%) than naturally reared fish (7.3%). We also found significant differences in straying of hatchery fish based on rearing type, stock, size at release and release location with more straying in Feather and American River stock, post-smolts and releases in the Bay-Delta. Of the hatchery strategies examined, releasing Mokelumne origin smolts in the Mokelumne River will minimize potential impacts to natural populations of chinook salmon.

Mokelumne River chinook salmon, *Oncorhynchus tshawytscha,* are considered part of the Central Valley fall-run evolutionarily significant unit (ESU) which is composed of populations that enter the Sacramento and San Joaquin Rivers from July through March and spawn from October through March (Myers et al. 1998). Fish in this ESU are ocean-type chinook salmon, emigrating predominately as fry and subyearlings (smolts and post-smolts) that remain off the California coast during their ocean migration. In this ESU, hatcheries account for 20% of the spawning escapement; hatchery strays spawning in the wild may account for another 30% of the spawning escapement; and, relatively high ocean and freshwater harvest rates may threaten sustainability of the naturally spawning populations (Myers et al. 1998).

Production hatcheries play a major role in supplying Pacific salmon to commercial, sport and tribal fisheries, and in the past have played a role in slowing the decline of natural populations (Flagg et al. 2000). East Bay Municipal Utility District (EBMUD) operates Pardee and Camanche reservoirs on the Mokelumne River in central California to provide water for municipal, irrigation, recreation, hydropower and fisheries uses, and to provide flood control protection. Completion of Camanche Dam in 1964 inundated about 16 km of salmon and steelhead, *O. mykiss*, habitat directly downstream of Pardee Dam. The Mokelumne River Fish Hatchery (MRFH) was constructed in 1964 to mitigate for the construction and operation of Camanche Dam and reservoir and produces fall-run chinook salmon to supplement natural production and maximize ocean harvest. The facility is owned by EBMUD and operated and maintained by the California Department of Fish and Game (CDFG).

Hatchery production practices can result in a number of potential risks to natural populations, including compromising the genetic integrity by unintentional breeding of straying hatchery fish (Reisenbichler and Brown 2003) and artificially increasing ocean harvest rates to a point that could drastically reduce natural stocks (Labelle et al. 1997). We examined the effect of various release strategies currently employed at the MRFH on escapement, ocean harvest and straying and compared those to naturally reared fish to determine which strategies minimize impacts to natural populations.

Methods

Coded wire tagging is routinely used to identify groups or populations of salmon (Mortensen et al. 2002). Standard coded wire tagging methods as described in Hale and Gray (1998) were followed for the tagging of hatchery and naturally reared fish.

Release reports were prepared after the salmon were released from the hatchery and naturally reared fish were coded wire tagged (tagged) and released, and submitted to the Pacific States Marine Fisheries Commission's (PSMFC) Regional Mark Information System. Data on tagged fish recoveries from 1991 through 2002 were obtained from the PSMFC and from unpublished raw data from the California Department of Fish and Game (M. Erickson, pers. comm., 2003).

Hatchery release strategies included brood stock origin (Feather, American and Mokelumne rivers), size at release (smolts, post-smolts and yearlings), and release location (Bay-Delta and the Mokelumne River). Mokelumne River brood stock enters the MRFH as adults. Feather and American river fry were imported from brood year 1990 through 1993 and 1997; eggs were imported from brood year 1994 through 1996 and 1998, 1999. Fish were tagged and adipose fin-clipped (marked) from 1991 through 2000 (brood years 1990 through 1999) as smolts. Smolt releases, defined as at least 132 fish/kg by hatchery personnel, were conducted between 4 April and 20 May and fish ranged in size from 66 to 89 mm fork length (FL). Hatchery personnel define post-smolts as less than 132 fish/kg. Post-smolt releases occurred from 12 April to 8 July and fish ranged in size from 81 to 115 mm (FL). Yearlings are defined as those raised in the hatchery through the summer. Yearling releases occurred between 14 September and 17 November and fish ranged from 146 to 189 mm (FL). Release locations included seven sites in the Bay-Delta (Benicia, Carquinez Strait, Crockett, Jersey Point, Rodeo Minor Port, Sherman Island, and Wickland Oil Net Pen) and 6 sites in the Mokelumne River (MRFH, Woodbridge Irrigation District Dam, New Hope Landing/Thornton, North Fork Mokelumne River, South Fork Mokelumne River, and Mouth of the Mokelumne River) (Figure 1).

Naturally reared fall-run chinook salmon were captured in rotary screw traps and in an incline plane trap during annual outmigration monitoring conducted by EBMUD at the Woodbridge Irrigation District Dam (WIDD). WIDD is an irrigation impoundment at River km 63, which consists of a flashboard dam, a two-stage fish ladder for passage, and a bypass pipe, which conveys fish from the diversion intake to downstream of the dam. These fish were tagged and marked on site and released immediately downstream. Fish were captured and tagged in 1993-2000, between 25 January and 2 August. Tagged fish ranged in size from 37 to 115 mm (FL). We assumed all fish captured were produced from fish spawning naturally in the lower Mokelumne River, however, the MRFH is located immediately below Camanche Dam (River km 103) on the Mokelumne River and some captured juvenile salmon may have escaped from the hatchery.

Analysis of escapement and straying utilized recoveries from inland hatcheries, freshwater sport, spawning grounds, traps and weirs, and creel surveys, and analysis of ocean harvest included recoveries by sport, ocean sport, estuary sport, ocean troll, groundfish observers, ocean trawl by-catch and treaty troll harvests (Pacific Salmon Commission fishery codes).

Straying rates are expressed as the ratio of adults recovered outside the Mokelumne River to the total number of adults recovered for each strategy and include an approximate 95% confidence interval (Zar 1996). We used a contingency table chi-square test to analyze the effects of individual factors (stock origin, release size, release location, and naturally-produced fish) on inland and ocean recoveries, and also Mokelumne River recoveries and other inland recoveries (straying) (Zar 1996). Minimum sample sizes required to detect a true population difference between two proportions with probabilities of α (0.05) and β (0.10) were determined for each test (Zar 1996). Only tests with adequate sample sizes are reported.

Results

Approximately 4,005,811 juvenile chinook salmon of various stock origins were raised at the MRFH, tagged and marked as smolts, and released at various sizes and locations between April 1991 and September 2000. Approximately 231,207 naturally reared fish produced in the lower Mokelumne River were captured, tagged and released in the lower Mokelumne River at Woodbridge Dam between May 1993 and July 2000. There were 7,581 tagged fish recovered in the ocean, and 6,265 recovered at inland locations. Most of the inland recoveries were captured in the Mokelumne (4,214), American (1,395), Feather (439) and Merced (174) rivers, with the majority recovered as hatchery returns at the MRFH (4,186), Nimbus Fish Hatchery on the American River (1,338), Feather River Fish Hatchery (419) and the Merced River Fish Hatchery (172) (Figure 2). Forty-three tagged fish were recovered from the Sacramento River (14), Yuba River (14), Tuolumne River (5), Clear Creek (4), Mill Creek (4), Stanislaus River (1) and Smith River (1).

Effect of Rearing Type, Stock, Size at Release and Release Location on Recovery Location

We found a significant difference in the frequency of inland and ocean recoveries based on rearing type, with a greater proportion of hatchery reared fish (all strategies combined) recovered in the ocean harvest than naturally reared fish (Table 1). However, a significantly greater proportion of naturally reared fish were recovered in the ocean harvest than Mokelumne River stock smolts released in the Mokelumne River. The frequency of ocean and inland recoveries was also significantly different for stock origin of hatchery fish, with a greater proportion of Feather and American River stock recovered in the ocean harvest than Mokelumne River stock. The frequency of ocean and inland recoveries of hatchery fish was significantly different for size at release with a greater proportion of post-smolts recovered in the ocean harvest than yearlings and smolts. Sample size was too small to compare smolts and yearlings. The frequency of ocean and inland recoveries was also significantly different for release location of hatchery fish, with a greater proportion of Bay-Delta releases recovered in the ocean harvest than Mokelumne River releases.

Effect of Rearing Type, Stock, Size at Release and Release Location on Straying

We found a significant difference in straying rates (escapement to rivers other than the Mokelumne River) based on all factors; rearing type (hatchery and natural), stock origin, size at release and release location. Hatchery fish had higher straying rates than naturally reared fish regardless of stock, release size or release location (Table 2). Feather and American River stocks strayed more than Mokelumne River stock. For size at release, post-smolts strayed more than smolts, but sample size was too small to compare yearlings. Finally, for release location, more Bay-Delta releases strayed than Mokelumne River releases.

Discussion

Our results indicate that certain hatchery strategies (brood stock origin, size at release and release location) currently practiced at the MRFH may affect natural populations of fall-run chinook salmon.

Effect of Rearing Type, Stock, Size at Release and Release Location on Recovery Location

Labelle et al. (1997) reported that hatchery-produced coho salmon, *O. kisutch*, were subject to higher exploitation than their natural counterparts, and speculated that hatchery chinook salmon feed less discriminately than naturally reared salmon and are more readily caught by hook and line in later life. Our results appear to support this conjecture, as naturally reared fish were proportionally less frequent in ocean harvest recoveries than hatchery fish (all strategies combined).

Labelle et al. (1997) also found that the effects of genetic makeup of coho salmon can outweigh the effects of hatchery conditioning on survival and recommended that the same parent stock be used when comparing the performance of hatchery and non-hatchery stocks. We found that the frequency of ocean and inland recoveries was significantly different for hatchery and naturally reared fish with a greater proportion of naturally reared fish recovered in inland rivers, however, hatchery reared, Mokelumne stock smolts released in the Mokelumne River showed a significantly greater proportion of recoveries in inland rivers than naturally reared fish.

Hatchery practices can influence subsequent fishery contributions (Bilton et al. 1982 and 1984). Bugert et al. (1997) found that fall-run chinook salmon released as yearlings contributed to escapement and to the Pacific Ocean and lower Columbia River fisheries at consistently higher rates than subyearlings released the same year, regardless of release location. Hemmingsen et al. (1986) found that more hatchery coho salmon returned to the hatchery from all juvenile fish released in July than from age-1 fish released in May. We found that post-smolts provided a significantly greater proportion of ocean harvest recoveries than smolts and yearlings, which showed a greater contribution to escapement.

Reisenbichler (1988) determined that the distance transferred from the natal stream was negatively related to recovery rate for hatchery-reared coho salmon. Our data showed a significantly greater proportion of recoveries in the ocean harvest of hatchery reared chinook salmon when they were released in the Bay-Delta than when released in the lower Mokelumne River.

Effect of Rearing Type, Stock, Size at Release and Release Location on Straying

Although straying is a natural behavior that enables salmon to colonize new habitat and avoid locally unfavorable conditions (Milner and Bailey 1989, Leider 1989), straying of hatchery fish concerns fishery managers because of the potential negative impacts on natural populations. A number of factors have been documented as contributing to straying in both naturally reared and hatchery salmon stocks, including time of release (Pacual et al. 1995) and location of release (Pascual and Quinn 1994).

Little is known about straying in naturally reared salmon populations and most of the estimates of straying come from studies of hatchery fish (Quinn 1997). Thedinga et al. (2000) found that straying rates were low (5.1%) for two stocks of naturally reared pink salmon, *O. gorbuscha*, but tagged fish had a higher incidence of straying than fish that were pelvic-fin clipped. McIsacc (1990) found that naturally reared juvenile fall-run chinook salmon strayed at a lower rate than members of the population that had been incubated and reared in the hatchery. We found that naturally reared fish strayed at a rate of 7.3% compared to 33.6% in hatchery fish (all strategies).

The practice of transporting eggs and juvenile salmon from out-of-basin to incubate and/or rear in Mokelumne River Hatchery and subsequent release in the Mokelumne River has occurred from the start of operation of the hatchery through brood year 1999. We found that the straying rate of Mokelumne River origin stock was 25.9% compared to 66% for Feather River and American River stocks combined.

The timing of release also influences straying. Fish released too early might be expected to stray due to limited time to imprint, or because their endocrine physiology is not synchronized with migration (Quinn 1997). Pascual et al. (1995) found much higher straying rates for early and late releases than intermediate release dates. They concluded that imprinting might be based both on the time the fish spends at a location (time in the river) and the physiological condition at which the fish experiences that location. Changes in release dates may disrupt the sequence necessary for proper imprinting. We found that only 22.6% of smolts strayed compared to 45.7% of post-smolts.

Quinn (1993) found that as the distance from the rearing facility and the release site gets closer, larger numbers of salmon return to the rearing facility, especially if the facility and release site are in the same watershed. Our research indicated a significant difference in the straying rate of fish released in the lower Mokelumne River (16.7%) and those released in the Bay-Delta (71.3%). Our results are consistent with the findings of Pascual and Quinn (1994) who found that chinook salmon released in tributary streams in the estuary of the Columbia River had higher straying rates than those released farther upstream, and suggest that a longer period of time, or longer migration distance through freshwater may improve homing and imprinting for chinook salmon (Thedinga et al. 2000).

Knowledge of hatchery practices that influence escapement, ocean harvest and straying is important for modifying hatchery programs to improve escapement, ocean harvest and reduce the potential impacts on naturally reared populations. Our study indicates that naturally reared Mokelumne River chinook salmon have had a significantly lower straying rate than hatchery salmon and contribute more to inland recoveries compared to hatchery reared fish. We found that hatchery post-smolts released in the Bay-Delta contribute a greater proportion to the ocean harvest, while the release of hatchery smolts and yearlings in the Mokelumne River provide a greater contribution to escapement. Bay-Delta releases may contribute to high ocean harvest rates that could reduce the abundance of natural populations to levels that are insufficient for maintaining genetic viability. Using local brood stock, releasing the fish as smolts, and releasing the fish in the Mokelumne River could reduce straying of MRFH reared fish and reduce the impacts on the natural population.

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Table 1. Comparison of inland and ocean recovery rates of naturally reared chinook salmon and various hatchery release strategies

Stock	Size at Release	Release Location	Inland/Ocean Recovery Ratio	*P*
Naturally reared	All Sizes	Mokelumne River	1.35	
All Hatchery Stocks	All Sizes	All locations	0.82	<0.0001
Feather and American River	All Sizes	All Locations	0.51	<0.0001
Feather and Mokelumne River	Post-smolt	All locations	0.60	<0.0001
Mokelumne River	Smolt	Mokelumne River	2.13	<0.001
Feather and Mokelumne River	All Sizes	Bay-Delta	0.46	<0.0001
Mokelumne River	All Sizes	All locations	0.95	
Feather and American River	All Sizes	All locations	0.51	<0.0001
Feather and Mokelumne River	Post-smolt	All locations	0.60	
Feather and Mokelumne River	Smolt	All locations	1.41	<0.0001
Mokelumne and American River	Yearling	Mokelumne River	1.19	<0.0001
Feather and Mokelumne River	All Sizes	Bay-Delta	0.46	
All hatchery stocks	All Sizes	Mokelumne River	1.28	<0.0001

Table 2. Comparison of straying rates of naturally reared fall-run chinook salmon and various hatchery release strategies

Stock	Size at Release	Release Location	% Straying Rate (95% CI)	*P*
Naturally reared	All Sizes	Mokelumne River	7.3 (4.5-13.8)	
All hatchery stocks	All Sizes	All locations	33.7 (33.2-34.3)	<0.0001
Feather and American River	All Sizes	All locations	66.0 (62.8-68.0)	<0.0001
Mokelumne River	All Sizes	All locations	25.9 (25.4-26.7)	<0.0001
Feather and Mokelumne River	Smolt	All locations	22.6 (21.6-24.8)	<0.0001
Feather and Mokelumne River	Post-smolt	All locations	45.7 (44.7-46.8)	<0.0001
Mokelumne River	Smolt	Mokelumne River	14.8 (13.7-15.9)	0.006
Mokelumne River	Post-smolt	Mokelumne River	16.9 (15.6-19.3)	0.0008
All hatchery stocks	All Sizes	Mokelumne River	16.7 (16.2-17.8)	0.0008
Feather and Mokelumne River	Post-smolt	Bay-Delta	71.3 (68.9-72.7)	<0.0001
Mokelumne River	All Sizes	All locations	25.9 (25.4-26.7)	
Feather and American River	All Sizes	All locations	66.0 (62.8-68.0)	<0.0001
Feather and Mokelumne River	Smolt	All locations	22.6 (21.6-24.8)	
Feather and Mokelumne River	Post-smolt	All locations	45.7 (44.7-46.8)	<0.0001
All hatchery stocks	All Sizes	Mokelumne River	16.7 (16.2-17.8)	
Feather and Mokelumne River	Post-smolt	Bay-Delta	71.3 (68.9-72.7)	<0.0001

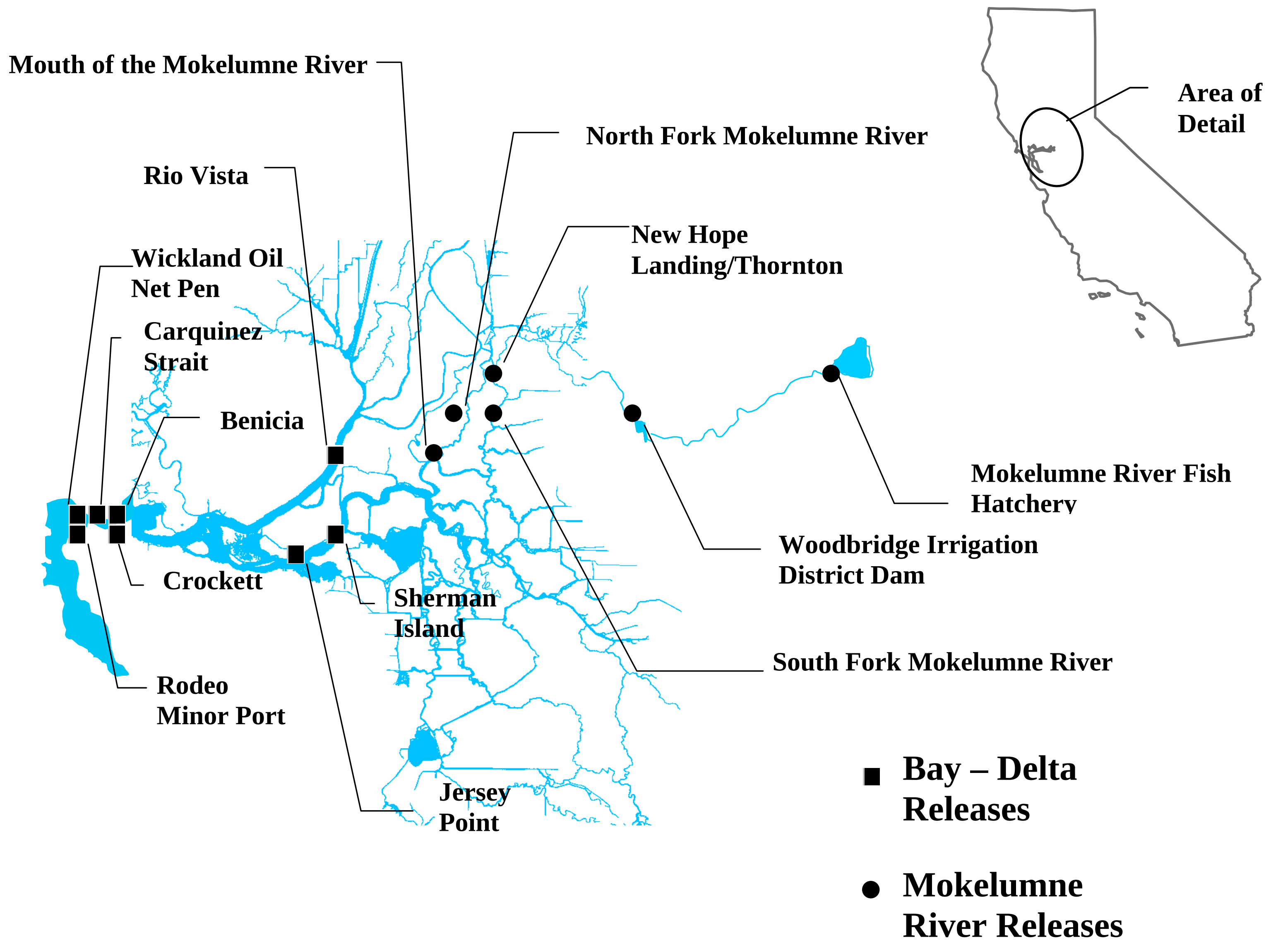

Figure 1. Release locations of coded wire tagged fall-run chinook salmon reared at the Mokelumne River Fish Hatchery

Figure 2. Inland recovery locations of coded wire tagged fall-run chinook salmon