Hatchery and natural *Oncorhynchus mykiss* emigration from the lower Mokelumne River, California:
Distance traveled, migration rates, and paths to the Pacific Ocean

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INTRODUCTION

Steelhead *Oncorhynchus mykiss* are perhaps the most widespread native salmonid in California. They are successful because they have adapted to a wide variety of habitats and have flexible life history patterns including both resident and anadromous forms. Unlike Pacific salmon, steelhead may survive spawning and make repeated migrations. Furthermore, they are relatively easy to propagate, making them one of the most popular planting fish in the state. Even so, many populations have seen dramatic declines over the past half-century and are now listed under the Federal Endangered Species Act.

Steelhead once ranged throughout many of the tributaries and headwaters of the Central Valley (CV). Today, the majority of CV steelhead are restricted to non-historical spawning and rearing habitat below dams. Steelhead are difficult to monitor because they often migrate and spawn during periods of high, turbid waters and over protracted periods at relatively low densities. Furthermore, juveniles often migrate at larger sizes, making them less susceptible to the most common monitoring techniques.

In this study we employed acoustic telemetry to compare movement and macrohabitat use of Mokelumne River steelhead of natural and hatchery origin at various life stages (>180 mm FL). In winter 2007, we tagged hatchery smolts and released them within the tidal delta. We also tagged hatchery kelts and released them adjacent to the hatchery. Concurrently, we collected wild and residual hatchery steelhead by boat electrofishing, and released them at original capture locations throughout the non-tidal Mokelumne River (within 20 km of Camanche Dam).

In the second phase of this study, January through May 2008, we again tagged hatchery smolts, hatchery kelts, and natural steelhead caught by electrofishing, and additionally implanted tags in actively-migrating natural and hatchery steelhead captured by rotary screw trap near Mokelumne River tidewater. Also, two Feather River steelhead were captured by hook and line and released in the non-tidal areas of the Feather River.

Here, we report information recovered on ten receiver stations deployed from the base of Camanche Dam through tidal Mokelumne River and the station grid located throughout the Sacramento-San Joaquin Delta and Estuary. No data is currently available on Feather River fish monitoring stations.

METHODS

STATIONARY RECEIVERS

We used Vemco VR2W monitoring receivers (submersible, single channel receiver) and Vemco coded transmitters. We deployed 10 acoustic receivers (Vemco VR2W – 69kHz) in the lower Mokelumne River from the base of Camanche Dam to the confluence with the San Joaquin River, the receiver recorded the identification number and time stamp from the coded acoustic transmitters as tagged fish traveled within receiver range. Data were downloaded monthly in the field using a wireless PC interface through 30 July, 2008. Members of the California Fish Tracking Consortium downloaded data similarly from over 300 receivers deployed throughout the Sacramento-San Joaquin River System, Delta and Bays.

MOBILE TRACKING

Standardized transects to monitor tagged fish locations were traveled in a 12 ft aluminum skiff with a Vemco handheld acoustic hydrophone and VR60 or VR100 receiver for approximately 38 km, from Camanche Dam to the town of Lodi. Transects were traveled in random intervals of approximately 2 weeks from Feb 2007 through Mar 2009. 2008 transects were traveled twice, four concurrent days in a row, to test for daily movement rates. The transect was traveled no faster than 90 seconds per range of the receiver, to ensure detection and enable population level habitat associations and analysis. No mobile tracking was conducted on the Feather River for this portion of the study.

Table 1. The number and type of *O. mykiss* tagged acoustically in the lower Mokelumne River, California, over a two-year period. Release locations are the same as capture locations except for hatchery smolts. See Figure 1 for corresponding locations.

Year	Release Period	Fish classification	Release location	Number	Mean Length (mm)
2007	February	Hatchery smolts	New Hope	57	214 (stdev 27)
	February	Kelts	adjacent to hatchery	7	535 (stdev 65)
	Feb & May	Natural *O. mykiss*	lower river above tidewater	64	301 (stdev 82)
			2007 total	128	
2008	January	Hatchery smolts	Antioch	35	220 (stdev 12)
	February	Hatchery smolts	San Pablo (Selby)	35	219 (stdev 17)
	February	Kelts	adjacent to hatchery	10	506 (stdev 46)
	April	Hatchery smolts	adjacent to hatchery	30	252 (stdev 24)
	Feb-Apr	migrating *O. mykiss*	Upper RST	4	216 (stdev 22)
	Feb-Apr	migrating *O. mykiss*	Lower RST	10	256 (stdev 62)
	Feb-May	Natural *O. mykiss*	lower river above tidewater	55	266 (stdev 63)
			2008 total	179	
			Grand Total	307	

TAGGING and RELEASE

We implanted Vemco acoustic transmitters in 307 Mokelumne River hatchery, natural and post-spawn kelt *O. mykiss* between 2007 and 2008 (Table 1). Tagged hatchery fish were released with 356,900 2006-brood-year *O. mykiss* produced at the Mokelumne River Fish Hatchery in 2007 and approximately 277,000 2007-brood-year *O. mykiss* in 2008. Kelts were released in the river below the hatchery. River-caught *O. mykiss* of various life stages (FL >180 mm) were captured, tagged and released at various locations throughout the non-tidal lower Mokelumne and Feather rivers in the winter and spring of 2007 and 2008 by hook and line and electrofishing (Table 1).

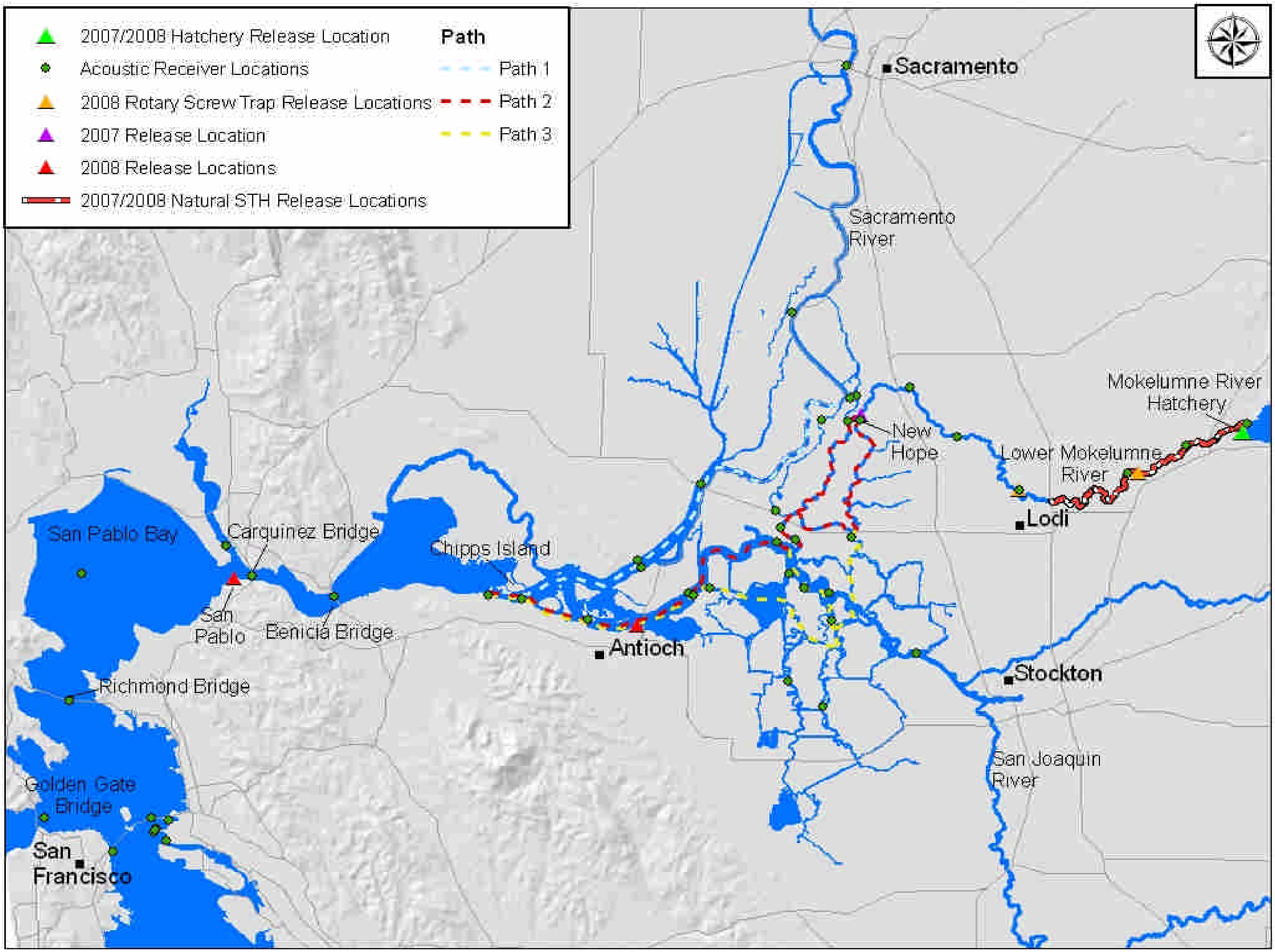


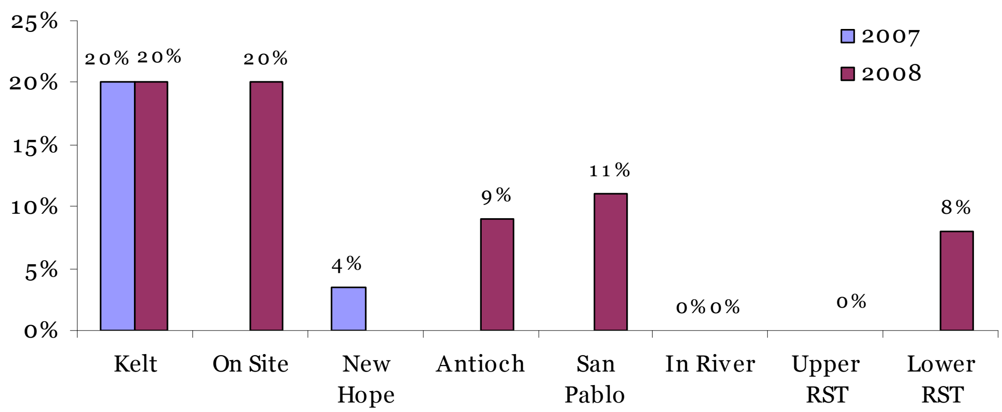
Figure 1. Map of selected stationary monitoring and release locations of Mokelumne River hatchery and natural *O. mykiss* for 2007 and 2008.

In 2008 on the Mokelumne River, we also captured *O. mykiss* during rotary screw trap operations at two locations (Rkms 62 and 87) and tagged and released fish >180mm FL at the trapping locations.

DATA ANALYSIS

We compared net movement direction by fish classification across years using contingency table analysis (Chi square) (see Table 1 for fish classifications). We compared mean maximum migration distance of fish using ANOVA by fish classification. We also compared migration rates (mean kilometers per day), using ANOVA, for each fish classification.

We compared the migration paths for each fish classification by tracking pathways of fish that were released in the Mokelumne River at New Hope or upstream and were successful at reaching Chipps Island (see Figure 1). These pathways were: 1) through the Delta Cross Channel and down the Sacramento River (blue); 2) down the Mokelumne River forks to the San Joaquin River (red) and; 3) down the Mokelumne River forks and through Potato Slough (yellow). At the time of this update there were no data available on pathways utilized or movement direction of Feather River steelhead.



Release Group	**Origin**	**Description**
Kelt	Hatchery	post spawned and reconditioned at Hatchery
On Site	Hatchery	smolts released in River below Hatchery
New Hope	Hatchery	smolts released in Delta
Antioch	Hatchery	smolts released at Antioch
San Pablo	Hatchery	smolts released at Selby
In River	Natural	tagged and released in River
Upper RST	Mixed	smolts tagged/released at rotary screw trap above tide water
Lower RST	Mixed	smolts tagged/ released at rotary screw trap at tide water

Figure 2. Proportion of acoustically tagged Mokelumne River *O. mykiss* that successfully migrated to the Golden Gate Bridge by release group.

RESULTS

Over the 2-year period (2007 and 2008), we acoustically tagged 307 *O. mykiss* of hatchery and natural origin (Table 1) on the Mokelumne River and two *O.mykiss* on the Feather River. On the Mokelumne we observed one or more detections on 260 (85%) of these fish, with 47 fish (15%) never being detected after release. No natural origin *O. mykiss* were observed successfully migrating to the Golden Gate Bridge in the 2-year study. The two natural *O. mykiss* tagged on the Feather River showed no large movements, displaying characteristics of resident fish. For Mokelumne River fish, kelts and on-site hatchery releases were most successful (20%) at making it to the Golden Gate, followed by San Pablo (11%), Antioch (9%) Lower Rotary Screw Trap (8%), and New Hope (4%) releases

MIGRATION DISTANCE

Fish classification (Table 1) had a significant effect on net downstream movement of *O. mykiss* in 2007 ($F = 4.6712$; $df = 110$; $P = 0.0113$) and 2008 ($F = 16.2258$; $df = 136$; $P < 0.0001$). Kelts and hatchery smolts released adjacent to the hatchery made the greatest net downstream movement in 2007 and 2008 (70.5 and 76.2 km respectively). Natural *O. mykiss* demonstrated the smallest net downstream movement. In 2007, 6 out of 64 (9%) natural fish tagged in river moved to tidewater, although none were detected at the Golden Gate Bridge. In 2008, none of the 55 natural fish tagged in the river migrated downstream to tidewater. The two Feather River *O. mykiss* demonstrated little activity, moving 0.2 and 2.3 miles from their release location at 51 and 89 days, respectively. Even so, 11 natural *O. mykiss* were tagged that year by rotary screw trap with 18% demonstrating migratory behavior. Although none were detected at the Golden Gate Bridge, 1 natural smolt was detected at the Richmond Bridge (Figure 3). Three hatchery origin O. mykiss were also tagged at rotary screw traps. One of these fish was detected at the Golden Gate Bridge.

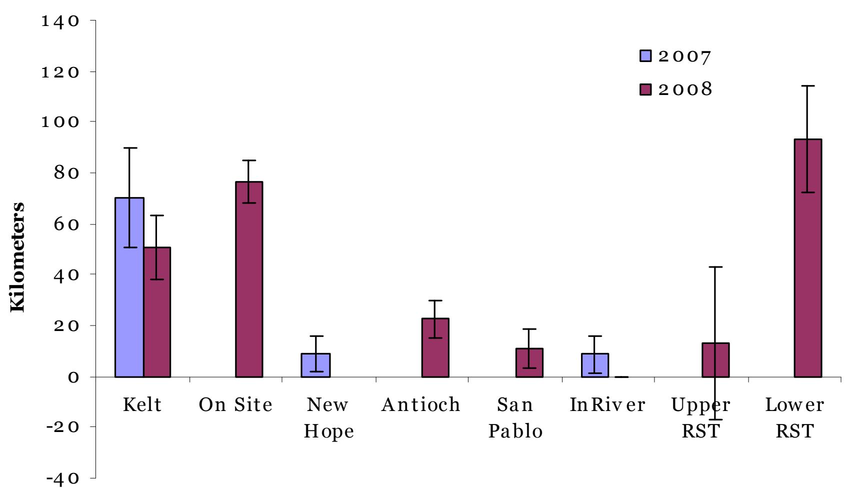


Figure 3. Net migration distance of acoustically tagged fish on the lower Mokelumne River by release group.

MIGRATION RATES
In 2007, migration rates were not significantly different for Mokelumne River *O. mykiss* based on release groups (F = 0.81; df = 2; *P* = 0.45) In 2008, release group had a significant effect on migration rate (F = 7.02, df = 6; *P* <0.0001) (Figure 4).

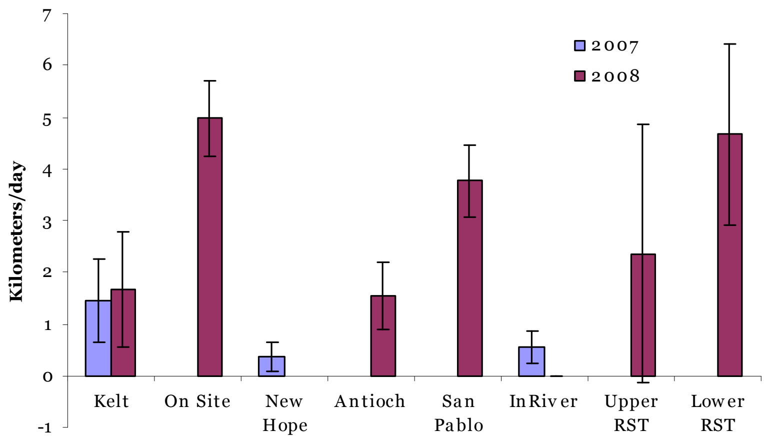


Figure 4. Net migration rate of acoustically tagged fish on the lower Mokelumne River by release group.

MIGRATION PATHS
Of the 32 fish that started above the Delta forks and migrated to Chipps Island, 9% used Path 1 via the Delta Cross Channel (Blue path), 66% used Path 2 (Red path), and 25% used Path 3 (Yellow path) including Franks Tract and the Stockton Deepwater channel to migrate downstream (Figure 5, see Figure 1).

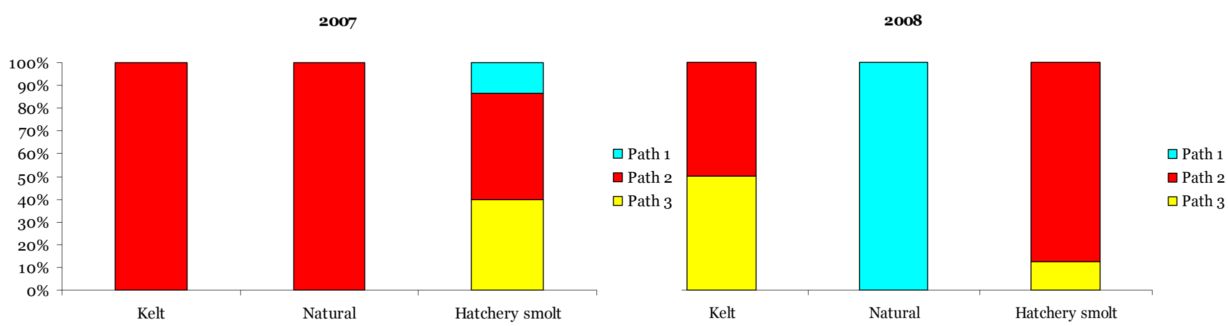


Figure 5. The proportion of fish, by classification, that started in the Mokelumne River above New Hope and migrated to Chipps Island using 1 of 3 pathways (see Figure 1)

MIGRATION DIRECTION
Fish classification had a significant effect on net movement of *O. mykiss* in 2007 (Chi square = 29.724; *P* <0.0001) and 2008 (Chi square = 128.097; *P* <0.0001). Overall, kelts displayed the highest net downstream movement. Hatchery smolts showed the greatest variability in movement direction and natural *O. mykiss* showed the least net movement (Figure 6).

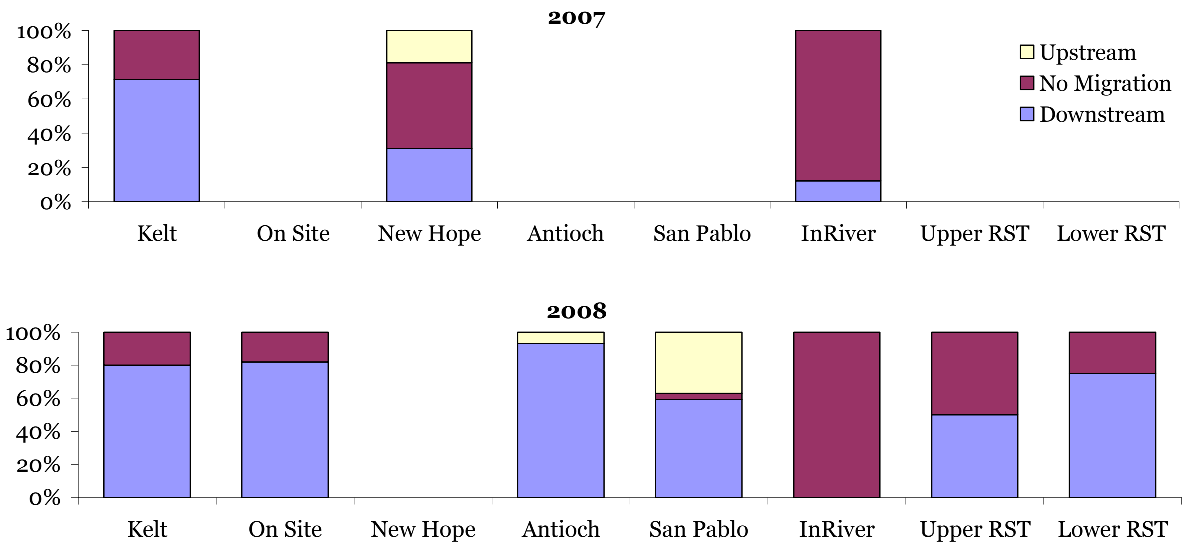


Figure 6. Net migration direction of acoustically tagged fish on the lower Mokelumne River by release group.

RECOMMENDATIONS

- **Expand research on the migratory component of natural origin *O. mykiss* from the lower Mokelumne River**

- **Expand research on pathway selection of emigrating Mokelumne River *O. mykiss* to assess Delta water management alternatives**

- **Continued assessment of hatchery release location effects on migratory paths, downstream migration potential, and successful returns of hatchery *O. mykiss* to the lower Mokelumne River**

- **Continued assessment of hatchery release location effects on the natural *O. mykiss* population is also recommended**

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