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The Natural Resources Agency
California Department of Fish and Wildlife

Pilot Evaluation of Barging Hatchery-Origin Juvenile Salmon from the California Central Valley through the Bay-Delta

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Executive Summary

California Central Valley (CCV) hatcheries produce roughly 32 million fall-run Chinook salmon annually, which supports a substantial proportion of the California recreational and commercial salmon fisheries. Many of the fall-run Chinook salmon produced and reared at hatcheries in the California Central Valley for mitigation and fishery enhancement are transported by truck and released into the California Bay-Delta. While these salmon have higher survival compared to in-river released fish, they also have higher stray rates when returning as adults. The transport of juvenile salmonid smolts by barge is a practice currently used in the Pacific Northwest. This approach was developed to reduce fish mortality, provide salmon an opportunity to acclimate to changing water conditions and imprint on the chemical signatures of the water from their basin of origin.

Recently, the California Department of Fish and Wildlife (CDFW) worked with partners to implement pilot evaluations for barging juvenile salmon from two state hatcheries, the Feather River Fish Hatchery, and the Mokelumne River Fish Hatchery. Barging smolts provides a means to bypass many sources of mortality and allow fish time to acclimate to changing water conditions. This approach may be beneficial in the California Central Valley where flow, water temperature, disease, and predation are considered limiting factors for outmigrating juvenile salmon. In addition, it has been hypothesized that barging may improve survival of hatchery produced juvenile salmon relative to in-river released fish (particularly during dry water years) and decrease stray rates among returning adults compared to trucked releases in the Bay. This study is the first attempt applying this approach in the California Central Valley. The objectives included determining the feasibility of transporting juvenile Chinook salmon by barge through the Central Valley and Bay-Delta and to compare adult recovery and straying rates between in-river releases, releases trucked to the Bay, and releases of barged salmon.

The barge used for transport of hatchery-origin Chinook salmon was the *Merva W*, a deep-water displacement vessel typically used as a commercial squid boat. Water quality parameters were monitored in the holding tank of the barge and compared to river, Delta, and Bay conditions during each trip. Barge travel time, distance and speed were also determined. The study fish consisted of fall-run Chinook salmon that were produced and reared at the Feather River and Mokelumne River hatcheries. At each hatchery, the study fish were divided into three marked and tagged groups of approximately 100,000 salmon. The release groups were trucked to a site in the hatchery basin (in-river) and released, trucked to the Bay, and released, or barged to the Bay and released. Standardized recovery rates for harvest, escapement and stray rates were calculated using the same definitions and formulas as previous annual CDFW constant fractional marking reports.

For the Feather River study, water quality parameters were similar between the barge holding tank and outside of the tank each year, except for pH and dissolved oxygen levels, which were consistently lower in the barge holding tank. However, supplemental oxygen was effectively used to maintain levels at or above 5.5 mg/L and dissolved oxygen and pH never fell to levels considered detrimental. The barge route was shortened each release year and in-river release locations changed due to drought conditions. These conditions diminished water quality

parameters and reduced river depth making it difficult for the barge to travel further upstream and to safely release fish in-river without losses. Each release year, the transport speed of the barge was roughly three to five times faster than documented outmigration rates of Chinook salmon smolts through the Sacramento River and Delta, which likely resulted in reduced time for olfactory imprinting. The total number of live, tagged salmon released varied by 7.0% or less, but there was some variation in the environmental and biological parameters associated with fish releases between and within years due to the drought, logistic constraints, and predation events.

The 2012-2014 Feather River release groups of juvenile fall-run Chinook salmon transported by barge had standardized harvest recovery rates (recoveries per 100,000 salmon released) of 1,035, 2,111, and 209, respectively. The recovery rates were similar to paired trucked Bay releases, which had harvest recovery rates of 1281, 2,036, and 224, respectively. The 2012-2014 in-river releases had harvest recovery rates that were similar to or lower than paired barged and Bay releases (958, 42, 216, respectively). Standardized CCV escapement recovery rates were similar between the 2012 in-river, Bay, and barge release groups (577, 448, and 536, respectively). Escapement recovery rates were also similar between the 2014 in-river, Bay, and barge release groups (347, 391, and 354, respectively). However, escapement recovery rates of the 2013 Bay and barge releases (1,710 and 2,012, respectively) were much higher when compared to the 2013 in-river release group (18). The annual variation in recovery rates among release groups was likely an artifact of *in situ* abiotic conditions. For example, the 2013 in-river release group encountered water temperatures ranging from 20-22.7°C through a long stretch of the Delta after being noted at release as weak and stressed. It is possible that release location and transport method played an important role in smolt to adult survival between the release groups.

The 2012 and 2013 releases of Chinook salmon transported by barge had adult stray rates of 19.7% and 27.7%, which were lower than the stray rates of the 2012 and 2013 paired Bay releases (28.5% and 35.8%, respectively). However, the 2012 and 2013 in-river releases had the lowest stray rates of 10.1% and 0%, respectively. These results were consistent with other studies in the Pacific Northwest (Keefer et al. 2008). The adult stray rates of all three 2014 release groups were similar and ranged between 0.6 and 3.7%. These rates are considered low when compared to previous releases of Feather River Hatchery salmon in the Bay.

For the Mokelumne River study, water quality parameters were similar between the barge holding tank and outside of the tank each year, except for dissolved oxygen and pH. Supplemental oxygen was effectively used to maintain levels at or above 5.5 mg/L and dissolved oxygen and pH never fell to levels considered detrimental. The barge route and in-river release locations were consistent during all three release years following the proposed study design. Each release year, the transport speed of the barge was roughly five to ten times faster than documented outmigration rates of Chinook salmon smolts through the Delta and Bay, which likely resulted in reduced time for olfactory imprinting. The total number of live, tagged salmon released varied by 4.4% or less between release groups.

The 2014, 2016, and 2017 Mokelumne River release groups of juvenile fall-run Chinook salmon transported by barge had standardized harvest recovery rates (recoveries per 100,000 salmon released) of 747, 1,950, and 629, respectively. The recovery rates of barged salmon were slightly higher than paired 2014, 2016, and 2017 trucked Bay releases, which had harvest recovery rates of 546, 1,545, and 552, respectively. The 2014, 2016, and 2017 in-river releases had harvest recovery rates that were much lower than paired barged and Bay releases (5, 110, and 202, respectively). Standardized CCV escapement recovery rates were highest for the 2014 and 2016 barged releases (506 and 1,681, respectively), when compared with recovery rates for paired Bay releases (171 and 934, respectively) and in-river releases (8 and 132, respectively). It is likely that in-river conditions and transport method contributed to the differences in smolt to adult survival between Bay, barged and in-river releases, as previous studies have documented low survival of outmigrating juvenile salmon through the Central and San Joaquin River Delta (Perry et al. 2010, Buchanan et al. 2013).

The 2014 and 2016 releases of Chinook salmon transported by barge had adult stray rates of 54.4% and 41.5%, which were lower than the stray rates of the 2014 and 2016 paired Bay releases (80.1% and 49.9%, respectively). However, the 2014 and 2016 in-river releases had the lowest stray rates of 0% and 7.2%, respectively. These results were consistent with the Feather River portion of this study and other studies in the Pacific Northwest (Keefer et al. 2008).

The pilot study demonstrated that barging juvenile salmon through portions of the Mokelumne River and Sacramento River outmigration routes is feasible on a small scale. Overall, the findings indicated that barging salmon to the Bay or releasing salmon directly in the Bay improved the rate at which adults contributed to harvest when compared to in-river releases, particularly in the Mokelumne River system. Barged salmon also had lower adult stray rates when compared with paired groups released in the Bay. However, the results were tempered by the increased straying rates of barged releases when compared to in-river releases. If resource managers consider barge transport as a release strategy in the future, it will be important to determine if the logistics and cost of an expanded barging program are prohibitive. This study also highlights the need to pursue and evaluate other strategies that may improve smolt to adult survival and reduce straying of naturally produced and hatchery origin salmon, such as adaptively managing Delta Cross Channel and pumping operations, improving river flows during critical migration periods, and continued habitat restoration activities.

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Introduction

Eleven fish hatcheries support the conservation and/or production of anadromous salmonids in California (California HSRG 2012). The California commercial and recreational salmon fisheries are largely supported by hatchery-origin fall-run Chinook salmon produced in the California Central Valley (Palmer-Zwahlen et al. 2018, Palmer-Zwahlen et al. 2019a, Palmer-Zwahlen et al. 2019b, Palmer-Zwahlen and Kormos 2020). California Central Valley (CCV) hatcheries produce roughly 32 million fall-run Chinook salmon annually. Fall-run Chinook salmon intended for mitigation or fishery enhancement may be released within the basin of origin, in the mainstem river along their migratory route, in the Bay-Delta, or along the Central California coast.

At present, many of the juvenile fall-run Chinook salmon produced and reared at state operated hatcheries in the CCV for mitigation and fishery enhancement are transported by truck and released into the California Bay-Delta. This approach was developed as a means of avoiding in-river fish losses due to predation, disease, high water temperatures, drought, State Water Project (SWP) and Central Valley Water Project (CVP) pumping operations, and unscreened water diversions. Survival of fish released into the Bay-Delta is further improved by using net pens to allow for fish orientation and acclimation prior to release (Palmer-Zwahlen et al. 2018, Palmer-Zwahlen et al. 2019a, Palmer-Zwahlen et al. 2019b, Palmer-Zwahlen and Kormos 2020). While trucked fish have higher survival compared to in-river released fish, they also have higher stray rates when returning as adults (Palmer-Zwahlen and Kormos 2020). The transport distance of hatchery-origin CCV juvenile salmon is strongly associated with straying of spawning salmon, but the relationship is not simple suggesting other factors are involved (Sturrock et al. 2019). The straying of Central Valley fall-run Chinook salmon from hatcheries to natural spawning areas has been considered as a factor that contributed to the homogenization of populations within the Central Valley fall-/late fall-run Chinook Salmon Evolutionarily Significant Unit (Williamson and May 2005, Lindley et al. 2009).

The transport of juvenile salmonid smolts by barge from upstream collection points to downstream release sites is a practice currently used in the Pacific Northwest. Barging juvenile Chinook salmon was first done on the Columbia River by the Washington Department of Fisheries from 1955 to 1958 (Ellis and Noble 1960). The National Marine Fisheries Service (NMFS) and the U.S. Army Corps of Engineers (USACE) Walla Walla District began barging juvenile salmon and steelhead on the lower Columbia River in the late 1970's (Harmon and Slatick 1989, McCabe et al. 1979). This approach was developed to reduce fish mortality and involves the collection and barging of juvenile salmon slowly downstream around dams and other sources of fish mortality. When transported by barge, salmon have an opportunity to acclimate to changing water conditions and may imprint on the chemical signatures of the water from their basin of origin.

Recently, the California Department of Fish and Wildlife (CDFW) North Central Region worked with partners to plan pilot evaluations for barging juvenile salmon from two state hatcheries, Feather River Fish Hatchery (FRH) and Mokelumne River Fish Hatchery (MRH). Barging smolts provides a means to bypass many sources of mortality and allow fish time to acclimate to changing water conditions. This approach may be particularly beneficial in the CCV where flow, water temperature, and predation are considered limiting factors for outmigrating juvenile salmon (Michel et al. 2015, Iglesias et al. 2017). In addition, barging has the potential to improve survival of hatchery produced juvenile salmon relative to in-river released fish (particularly during dry water years) and decrease stray rates among returning adults compared to trucked releases in the Bay. This study is the first attempt applying the approach of boat-based fish transport in the CCV.

Study Objectives

The purpose of this study was to evaluate the following questions:

1. Is it feasible to transport juvenile Chinook salmon by barge through the CCV and Bay-Delta?
2. Do juvenile fall-run Chinook salmon transported by barge have higher ocean harvest, freshwater harvest, and/or escapement recovery rates compared to in-river or Bay releases?
3. Do juvenile fall-run Chinook salmon transported by barge have lower stray rates compared to Bay releases?
4. What is the escapement distribution of salmon transported by barge compared to in-river and Bay releases?

Specific objectives of this pilot study included:

A. To develop and adjust methodologies for barging juvenile fall-run Chinook salmon through the CCV.
    - Identify the maximum upstream limit for transport vessel. For the FRH, possible sites included: Elkhorn, Verona, Broderick, or Rio Vista boat launch facilities depending on river conditions (water depth and space to maneuver). For the MRH, the transport barge upstream travel was limited to the Miller's Ferry Bridge on the North Fork of the Mokelumne River downstream of its divergence from the South Fork of the Mokelumne River.
    - Identify barge transport times, distance, and speed through the CCV and Bay-Delta. Travel times and speed may be affected by operational constraints, bridge operations, tidal conditions, and fish requirements for acclimation to changing water conditions.
    - Compare the water quality conditions of the barge holding tank to the water quality conditions of the river and Bay-Delta during salmon transport.

B. Summarize the physical and biological data associated with each study group including the number of fish released, fish losses, release date, release location, coded-wire tag (CWT) code, average fish weight, and release notes.

C. Examine and compare ocean harvest, freshwater harvest, and escapement recovery rates of the different release groups using data from CWT recoveries and assess the relative survival, stray rates, and escapement distribution of barged salmon compared to in-river and Bay released fish.

Methods

Study Area

The study area encompassed the CCV, the California Bay-Delta, and the coastal waters outside of the San Francisco Bay from Oregon to Southern California (Figure 1). Salmon used for the study were fall-run Chinook salmon smolts produced at the FRH, in Oroville, California and the MRH, in Clements, California. The FRH is located just below Oroville Dam, which impounds the Feather River. The lower Feather River remains accessible to anadromous salmonids and extends approximately 108 river kilometers (rkm) from the fish barrier dam to the confluence of the Sacramento River. The MRH is located just below Camanche Dam, which impounds the Mokelumne River. The lower Mokelumne River remains accessible to anadromous salmonids and extends 103 rkm from Camanche Dam through portions of the California Bay-Delta to its confluence with the San Joaquin River.

Transport Equipment

A truck equipped with a 10,600 L (2,800 gallons) tank was used to transport roughly 100,000 Chinook salmon smolts per trip from the hatchery to the study sites. However, in 2013 two trucks were used to transport Feather River study fish to the Bay to avoid any potential risk of overcrowding fish in one tanker as observed with the in-river and barge release groups. Metal pipe and additional flex tubing (20 cm in diameter) were used to gravity-release the salmon from the transport truck into the barge, net pens, or directly into the release waters depending on the study group.

The barge used for transport of FRH and MRH salmon was the *Merva W*, a 20 m (67 feet) deep-water displacement vessel with approximately 2.7 m (9 feet) of draft (Figure 2). The distance from water line to the top of the boat's mast is approximately 11 m (37 feet). The vessel has a holding tank capacity of 49,210 L (13,000 gallons) and can accommodate up to 55 tons of squid. The tank was divided into three separate sections, and only the middle section, 24,600 L (6,500 gallons) capacity, was used for holding fish. The middle holding tank dimensions were 2.7 m (length), 4.6 m (width), and 1.8 m (height). This single compartment allowed for easier unloading of salmon at the release site. The outlets from the holding tank were screened to prevent fish loss. Two separate pumps were operated continuously for water exchange and circulation during the trip to ensure fish were in good condition while in transport, provide an environment like river conditions, provide the opportunity for imprinting on water chemistry, and allow fish to acclimate to changing conditions. Photographs of the barge and other transport equipment are provided by the Photo Appendix.

Water Quality, Flow, and River Stage

Water quality parameters were monitored in the holding tank of the barge and compared to river, Delta, and Bay conditions during each trip. A YSI Model 85 meter, a HACH HQ40d meter, and/or an Oakton pH Testr3 meter was used to collect dissolved oxygen (mg/L), conductivity (uS/cm), temperature (°C), salinity (ppt), and pH every 30 to 60 minutes during transport from the barge departure location to the barge release (end) location. The water quality meters were calibrated prior to the project start date and field-calibrated during transport. If dissolved oxygen levels in the holding tank dropped too low, oxygen tanks and diffusers were used to

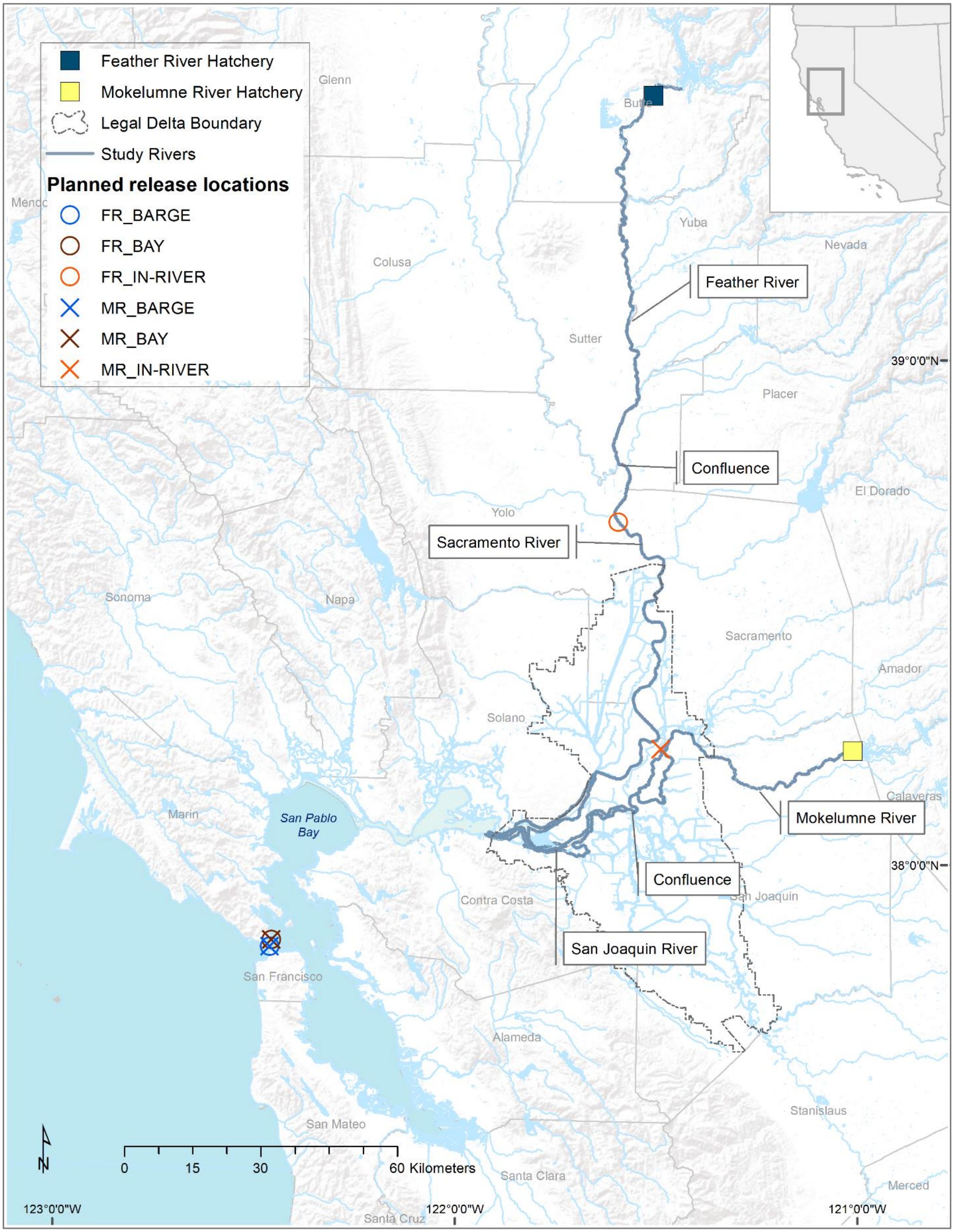

Figure 1. The California Central Valley and Bay-Delta including study rivers, planned release locations, and fish hatcheries that produced salmon for the study. FR = Feather River, MR= Mokelumne River.

Figure 2. A photograph of the *Merva W* and boat captain Michael McHenry. The *Merva W*, a commercial squid boat, was used to barge salmon during the pilot study.

increase dissolved oxygen levels. If water quality parameters differed significantly between the holding tank and outside river water, barge speed was reduced to allow greater time for conditions to equilibrate.

Data were downloaded from the California Data Exchange Center for gauges along or just upstream of the barging route within the stream of origin to determine river flow and stage during each barging event (CDEC 2020). For the Feather River study, data were downloaded from the Verona gauge on the Sacramento River (VON; 38.774, -121.598). For the Mokelumne River study, data were downloaded from the Mokelumne River gauge just upstream of the confluence with the San Joaquin River (MOK; 38.106, -121.571) and the North Fork Mokelumne River gauge near Walnut Grove Road (NMR; 38.223, -121.507).

Barge Route, Travel Time, Distance, and Speed

Estimated travel times for barging were determined by using approximate distances between bridges or significant locations along the route and assuming transport speed would average 8 km/hour (5 mph) (Appendix A). This information was used to help plan the study releases and barge timing each year. Barge travel time, distance and speed during project implementation was determined by utilizing the geographic coordinates (longitude and latitude) that were collected in conjunction with the water quality parameters during barging and the associated salmon releases. The information was used to calculate the distance, time, and the average speed of each barge segment and total travel distance and time. The waypoints (coordinates) were collected every 30-60 minutes and travel distance between each point was estimated using ArcMap 10.6.1 software. Within the CCV and Delta, the points were snapped to the nearest point along 100K routed hydrography to determine the position and distance along the route. Routed hydrography was not available in the San Francisco Bay, therefore the shortest distance between points (without hitting an obstruction or landmass) was calculated using 1:24,000-scale topographic maps as background imagery. A time stamp was associated with each point and average speed for each segment was calculated by dividing the distance traveled by the time elapsed.

Feather River

Study Fish

Feather River study fish consisted of fall-run Chinook salmon that were produced and reared at the FRH until they reached a size similar to previous Bay-Delta releases (8-10 g/fish or 45-60 fish/lb). The study fish were divided into three groups of approximately 100,000 salmon. The salmon were externally marked with an adipose fin clip and internally coded-wire-tagged using the AutoFish System™ (Vander Haegen and Blankenship 2010). Each study group was assigned a unique CWT code and marked and tagged at a rate near 100%. The study was repeated for three years, using FRH salmon produced from brood years 2011, 2012, and 2013.

Release Methods

The size of the transport barge and characteristics of the lower Feather River (extensive sand bars and shallow water) were expected to limit the upstream travel of the barge to the Sacramento River downstream of its confluence with the Feather River. In selecting starting points for barge transport, priority was given to proximity to the Feather River and distance from the American River. Releases for the three groups were planned as follows; 1) transport by truck from the FRH and directly release into the Sacramento River at the same location as the study group loaded onto the barge, 2) transport by truck from the FRH to Fort Baker and directly release into the San Francisco Bay, and 3) transport by truck from the FRH to the Sacramento River, transfer to the barge, and then transport by barge to Fort Baker and release into the San Francisco Bay (Figure 1). The releases for each study group took place within the closest possible proximity to like-releases from previous years. The releases were planned in April or May of each release year, but river temperatures and fish development influenced the timing of the release. Fish mortality was documented during truck or barge transport and upon release.

Mokelumne River

Study Fish

Mokelumne River study fish consisted of fall-run Chinook salmon that were produced and reared at the MRH until they reached a size similar to previous Bay-Delta releases (8-10 g/fish or 45-60 fish/lb). The study fish were divided into three groups of approximately 100,000 salmon. The salmon were externally marked with an adipose fin clip and internally coded-wire-tagged using the AutoFish System™ (Vander Haegen and Blankenship 2010). Each study group was assigned a unique CWT code and marked and tagged at a rate near 100%. The study was repeated for three years, using MRH salmon produced from brood years 2013, 2015, and 2016.

Release Methods

The size of the transport barge used in this study was expected to limit upstream travel to the Miller's Ferry Bridge on the North Fork of the Mokelumne River. The length and draft of the barge had a direct influence on the location selected to load fish for downstream transport. In selecting starting points for barge transport, priority was given to the most upstream location possible given the equipment limitations. Nautical charts were used to help select accessible locations and sites were surveyed each year prior to arrival to ensure accessibility and identify any unforeseen hazards. Releases for the three groups were planned as follows; 1) transport by truck from the MRH to the North Fork of the Mokelumne River at Miller's Ferry Bridge and release from a net pen, 2) transport by truck from the MRH to Fort Baker, transfer to the transport barge, and release directly with the barged fish at the Golden Gate Bridge, and 3) transport by truck from the MRH to the North Fork of the Mokelumne River near Miller's Ferry Bridge, and then transport by barge and release directly at the Golden Gate Bridge (Figure 1). The releases for each study group took place within the closest possible proximity to like-releases from previous years. The releases were planned in April or May of each release year, but river temperatures and fish development influenced the timing of the release. Any fish mortality was documented during truck or barge transport and upon release.

Release and Recovery Data

The Regional Mark Information System (RMIS) database was queried to obtain information associated with each tagged release group (RMIS online database). The release report generated by the RMIS online database (Barge Study Release Report 2020) and field notes during each barging event were used to produce a summary of all releases associated with the barge study. The field notes were used to provide additional information not available in the report such as release time, use of net pens, and estimated salmon losses during transport and release. Based on the field notes, salmon losses were estimated through observation or volumetric estimates (Appendix B). When specific numeric estimates were not provided, professional judgement was used based on the field notes.

The recovery data used for this analysis was provided by CDFW Marine Region staff and is summarized in annual constant fractional marking (CFM) reports (Palmer-Zwahlen et al. 2018, Palmer-Zwahlen et al. 2019a, Palmer-Zwahlen et al. 2019b, Palmer-Zwahlen and Kormos 2020, Letvin et al. 2020, Letvin et al. 2021).

A standardized recovery rate (R_{cwt}) for each tagged release group was calculated using the same definitions and formula as the annual CFM reports (Palmer-Zwahlen et al. 2018, Palmer-Zwahlen et al. 2019a, Palmer-Zwahlen et al. 2019b, Palmer-Zwahlen and Kormos 2020, Letvin et al. 2020, Letvin et al. 2021). To be consistent with previous CFM reports and because the CWT release groups were composed of approximately 100,000 fish each, the recovery rates are reported in recoveries per 100,000 CWT salmon released, as follows:

$$R_{cwt}=\sum_{j=1}^{l} CWT_{samp,\,j}/(\text{CWT release group size}/100{,}000),$$

where CWT_{samp} represents recoveries expanded by their location-specific sample expansion factor and where *j (=1,2,3…,l)* denotes recovery location.

Ocean Harvest

For the Feather River study, recoveries through run year 2019 (ages 2-5) were available and used for ocean harvest analyses. For the Mokelumne River study, recoveries through run year 2019 were also used for ocean harvest analyses. The age of recoveries examined for the 2014 releases was 2 to 5. However, the age of recoveries examined for the 2016 and 2017 releases were limited to ages 2-4 and ages 2-3, respectively. Incomplete broods were analyzed for the 2016 and 2017 Mokelumne River study releases because within-year results could still be evaluated, and completion of a preliminary report was considered a management priority. In addition, age-4 and age-5 recoveries represent a small component of the cohort and are not expected to significantly change the results (Palmer-Zwahlen et al. 2018, Palmer-Zwahlen et al. 2019a, Palmer-Zwahlen et al. 2019b, Palmer-Zwahlen and Kormos 2020, Letvin et al. 2020, Letvin et al. 2021).

CCV Inland Harvest and Escapement

Inland harvest and escapement recoveries were available and used through run year 2018. For the Feather River study, this included salmon ages 2 through 5. For the Mokelumne River study, the age of recoveries examined for the 2014 releases was 2 to 5. The 2016 and 2017 releases were limited to ages 2-3 and age 2 only, respectively. Because age 2 recoveries do not account for most adult returns (Palmer-Zwahlen et al. 2018, Palmer-Zwahlen et al. 2019a, Palmer-Zwahlen et al. 2019b, Palmer-Zwahlen and Kormos 2020, Letvin et al. 2020, Letvin et al. 2021), the 2017 release groups were excluded from inland harvest and escapement analysis. Incomplete broods were analyzed for the 2016 Mokelumne River study releases because within-year results could still be evaluated, and completion of a preliminary report was considered a management priority. Escapement distribution for each release group was visually depicted using coordinate data and look-up tables provided by the RMIS online database.

CCV Straying

Escapement recoveries from the CCV, as described above, were used to determine the stray proportions. Escapement recoveries were classified as strays using the same definition as previous annual CFM reports (Palmer-Zwahlen et al. 2018, Palmer-Zwahlen et al. 2019a, Palmer-Zwahlen et al. 2019b, Palmer-Zwahlen and Kormos 2020, Letvin et al. 2020, Letvin et al. 2021). For the Feather River study, any salmon recovered outside of the Feather River hatchery basin (FR hatchery basin includes the Yuba River) was considered a stray. For the Mokelumne River study, any salmon recovered outside of the Mokelumne River hatchery basin was considered a stray. CCV stray proportions for each CWT code (S_{cwt}) were calculated using the same definitions and formula as the annual CFM reports, as follows:

$$S_{cwt} = \sum_{p=1}^{o} CWT_{samp,p} \text{ (out of basin locations)} / \sum_{p=1}^{q} CWT_{samp,p} \text{ (all CCV locations)},$$

where CWT_{samp} represents recoveries expanded by their location-specific sample expansion factor, *p* denotes recovery location, *o* denotes the number of out-of-basin recovery locations, and *q* denotes the total number of recovery locations.

Results

Feather River

Water Quality, Flow, and River Stage

In 2012 and 2013, water quality parameters were collected at hourly intervals during barge transport except for the late-night and early hours between 2300 and 0600, when the barge sat idle in the Bay (Figure 3). In 2014, water quality parameters were collected on a continual basis, including times when the barge was anchored in the Bay.

During all three release years, water temperatures were similar between the barge holding tank and outside of the tank along the barging route (Figure 3). However, water temperatures varied between release years in the barge tank. In 2012, water temperature ranged between 12.6 and 18.4°C and averaged 16.2°C. In 2014, water temperature ranged between 14.1 and 17.8°C and averaged 16.2°C. Water temperatures were higher in 2013, ranging between 14.2 and 22.4°C and averaging 20.1°C.

Dissolved oxygen levels were consistently lower in the barge holding tank when compared to conditions outside of the tank along the barging route during each release year (Figure 3). Dissolved oxygen ranged between 1-3 mg/L lower in the barge tank than in the river and Bay-Delta. Dissolved oxygen levels also varied between release years in the barge tank. In 2012 and 2013, dissolved oxygen levels were lower, ranging between 5.00 and 7.59 mg/L and averaging 6.45 mg/L in 2012 and ranging between 4.38 and 7.69 mg/L and averaging 5.60 mg/L in 2013. In 2014, dissolved oxygen ranged between 6.24 and 8.97 mg/L and averaged 7.07 mg/L.

Salinity and conductivity were similar between the barge holding tank and outside of the tank along the barging route during each release year (Figure 4). However, salinity varied between release years in the barge tank. In 2012 and 2013, salinity was lower in the barge tank, averaging 7.3 and 7.6 ppt, respectively. In 2014, average salinity in the barge tank was 12.2 ppt. During each release year, pH was slightly lower in the barge holding tank when compared to conditions outside of the tank (Figure 4). In the barge tank, pH also varied between release years and was generally lower in 2013 when compared to 2012 and 2014.

River stage and flow were considerably higher at the Verona gauge on the Sacramento River during the 2012 barging event than in 2013 and 2014 (Figure 5). During the 2012 barging event, river stage at Verona was roughly 1.2 m (4 ft) higher than in 2013 and 2014, averaging 4.9 m (16.1 ft). Flow was over 200 cms (7,000 cfs) higher at the Verona gauge in 2012 than in 2013 and 2014, averaging 529 cms (18,681 cfs).

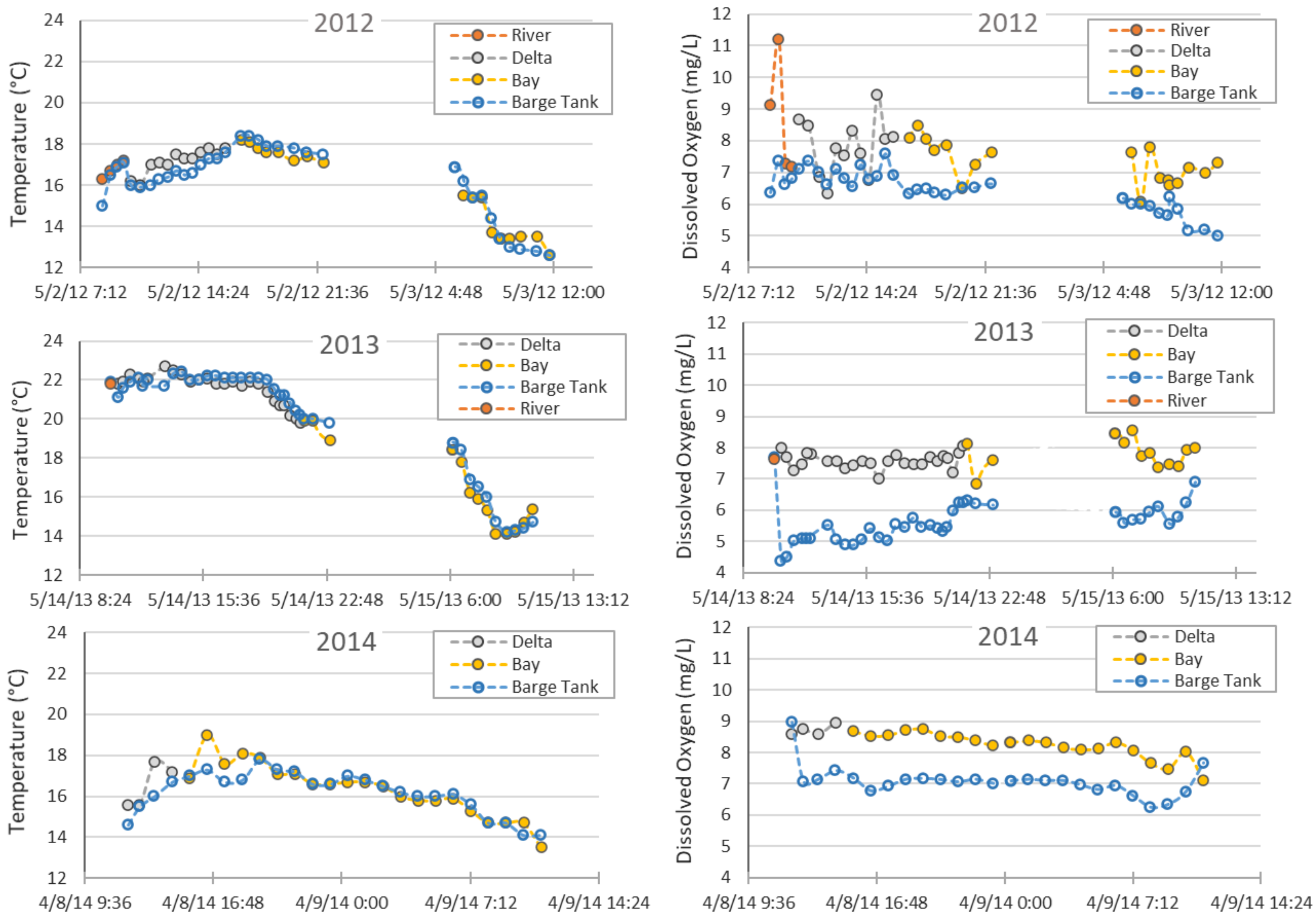

Figure 3. A comparison of water temperatures and dissolved oxygen levels by release year and between the barge tank and the water samples taken outside of the tank (River, Delta, and Bay) along the barging route for the Feather River study.

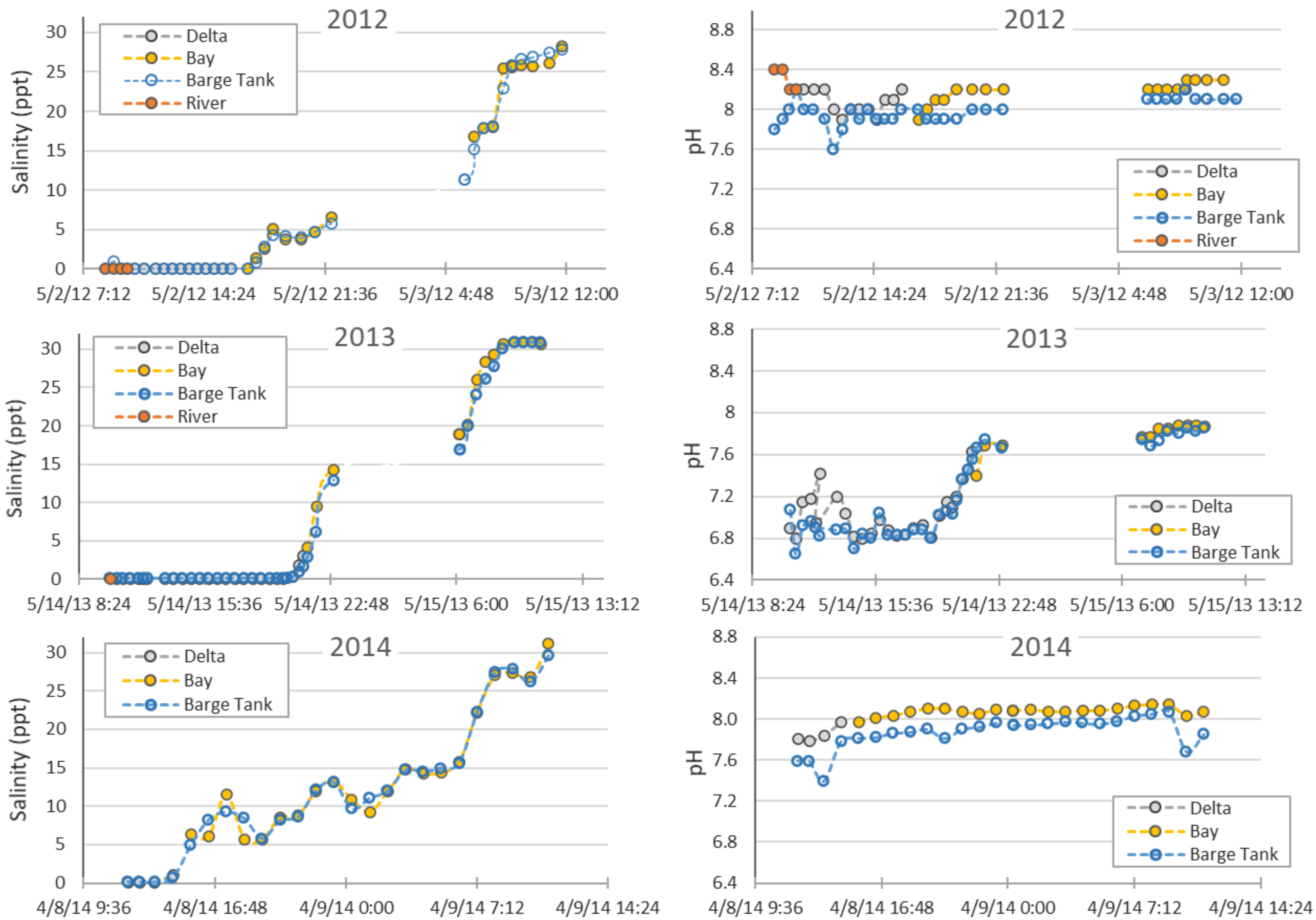

Figure 4. A comparison of salinity and pH levels by release year and between the barge tank and the water samples taken outside of the tank (River, Delta, and Bay) along the barging route for the Feather River study.

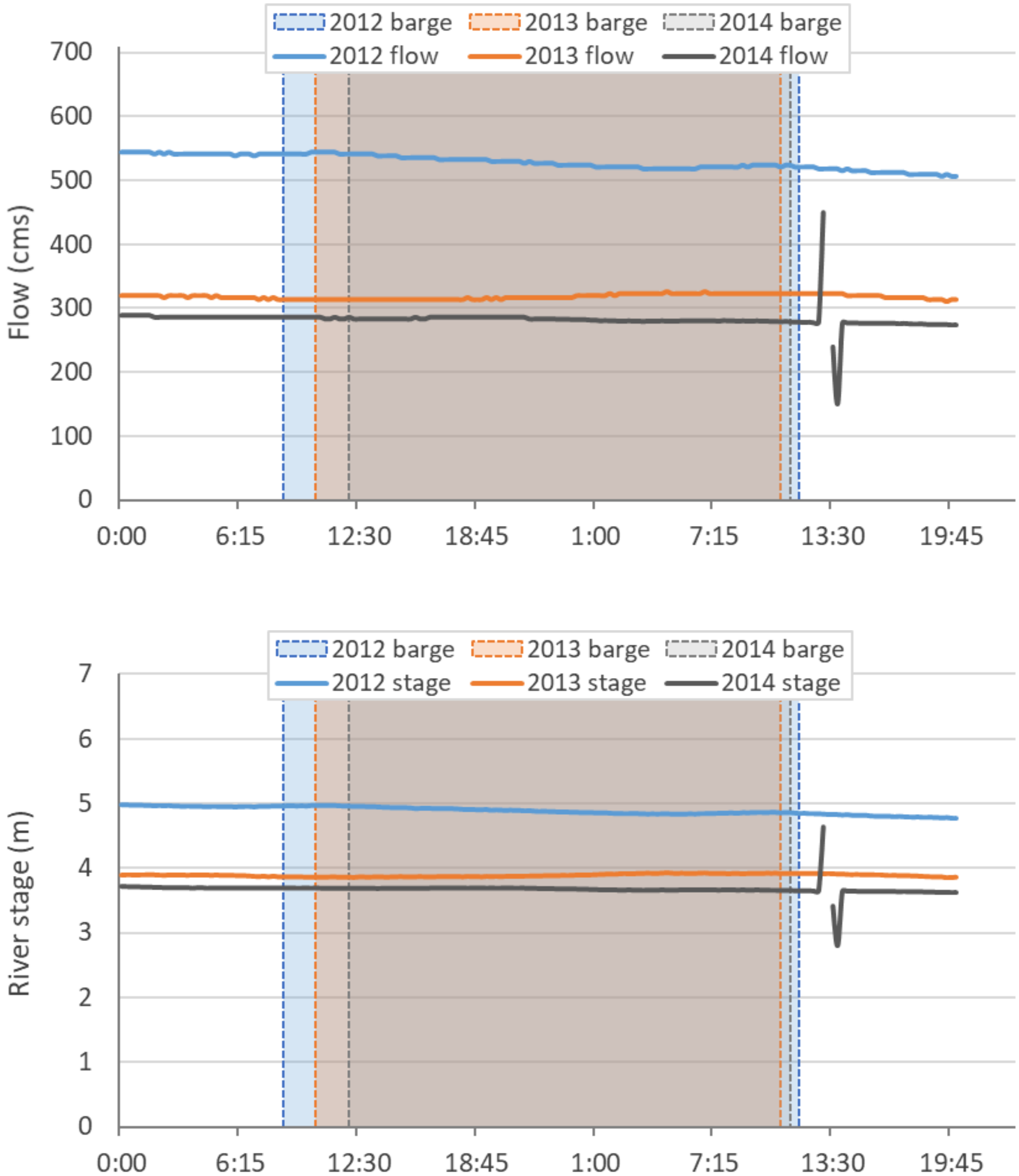

Figure 5. River flow (top) and stage (bottom) at the Verona gauge (VON) during the 2012-2014 barging events for the Feather River study.

Barge Route, Travel Time, Distance, and Speed

During the 2012 barging event, the maximum upstream extent of the route was determined to be the Elkhorn boat launch facility on the Sacramento River, downstream of the confluence with the Feather River. This launch site may be used when river stage exceeds 4.9 m (16 ft) at the Verona gauge (VON) on the Sacramento River (CDEC 2020). The river stage at VON measured 5 m (16.4 ft) at the beginning of transport. Based on this reading, the barge had only 0.6 m (2 ft) of clearance in some of the river sections between Elkhorn Boat Launch and the DART yard. Due to lower flows and river stages, starting points further downstream were used the following two years. In 2013 and 2014, the Broderick boat ramp in West Sacramento and the boat ramp in Rio Vista were the most upstream accessible launch facilities, respectively.

In 2012, the barge route covered approximately 188 km (117 mi.) through the river and Bay-Delta and took place over 28 hours including an overnight stop in the Bay (Benicia). The average speed of the barge was 4.2 km/h (6.7 mph) including all stopping time. The maximum speed of the barge over any given segment along the route was 14.7 km/h (23.8 mph) and the minimum speed over any moving segment was 6.2 km/h (10.0 mph).

The barge route was shorter in 2013 and covered approximately 170 km (106 mi.) through the river and Bay-Delta and took place over 24.6 hours including an overnight stop in the Bay (Benicia). The average speed of the barge was 4.3 km/h (6.9 mph) including all stopping time. The maximum speed of the barge over any given segment along the route was 13.1 km/h (21.2 mph) and the minimum speed over any moving segment was 1.7 km/h (2.7 mph).

In 2014, the barge route was significantly reduced due to drought conditions and covered 94 km (58 mi.), starting in the Delta. Barging took place over 23.4 hours including an overnight stop in the Bay (Benicia). The average speed of the barge was 2.5 km/h (4.0 mph) including all stopping time. The maximum speed of the barge over any given segment along the route was 12.5 km/h (20.2 mph) and the minimum speed over any moving segment was 2.0 km/h (3.2 mph).

Fish Releases

A summary of information associated with each release group during the Feather River study is provided by Table 1. Labels used to identify each release group are established in the column named Group ID. The average weight of the salmon in each release group varied by year. In 2012 and 2014 the salmon were smaller averaging 6.7 and 7.8 grams per fish. In 2013 the salmon in each release group were an average of 11.3 grams per fish. The release locations of each group varied between years (Table 1, Figure 6). Net pens were used for the in-river release groups in 2013 and 2014, but not in 2012. The variation in release locations and use of net pens was due to drought and other unforeseen logistics adjustments, which are further described in Appendix B.

The number of salmon in each release group prior to transport was near 100,000 and deviated between release groups by 2.5% or less. Tag (CWT and adipose fin-clip) rates were also similar

Table 1. A summary of Feather River study release groups including physical, biological, and other information associated with each group. FRH = Feather River Hatchery, CS= Chinook salmon, tagged = CWT and adipose fin-clip.

Group ID	Tag code	Hatchery origin	Brood year	Species (run)	Ave. weight (g)	Release date	Release time	Release location	Net pens used?	Number of salmon before transport	Number of salmon tagged	Tag rate	Estimated losses during transport & release	Number of tagged live salmon released
FR12_IN-RIVER	069502	FRH	2011	CS (fall)	7.55	5/2/12	8:40	Sacramento River at Elkhorn	No	100,232	99,901	0.997	0	99,901
FR12_BAY	069504	FRH	2011	CS (fall)	7.55	5/3/12	13:10	Fort Baker Pier	No	98,567	98,241	0.997	150	98,091
FR12_BARGE	068685	FRH	2011	CS (fall)	7.55	5/3/12	13:10	Fort Baker Pier	No	99,170	98,947	0.998	1,000	97,949
FR13_IN-RIVER	060471	FRH	2012	CS (fall)	11.33	5/14/13	10:55	Sacramento River at Broderick	Yes	99,400	96,832	0.974	0	96,832
FR13_BAY	060472	FRH	2012	CS (fall)	11.33	5/15/13	12:50	Fort Baker Cove	No	99,470	97,760	0.983	250	97,514
FR13_BARGE	060473	FRH	2012	CS (fall)	11.33	5/15/13	10:40	Fort Baker Cove	No	100,534	99,192	0.987	6,000	93,272
FR14_IN-RIVER	060572	FRH	2013	CS (fall)	7.55	4/8/14	13:45	Sacramento River at Rio Vista	Yes	100,092	99,354	0.993	500	98,858
FR14_BAY	060525	FRH	2013	CS (fall)	6.67	4/9/14	11:45	Golden Gate Bridge	No	100,227	100,227	1.000	250	99,977
FR14_BARGE	060524	FRH	2013	CS (fall)	6.67	4/9/14	11:45	Golden Gate Bridge	No	101,098	100,564	0.995	250	100,315

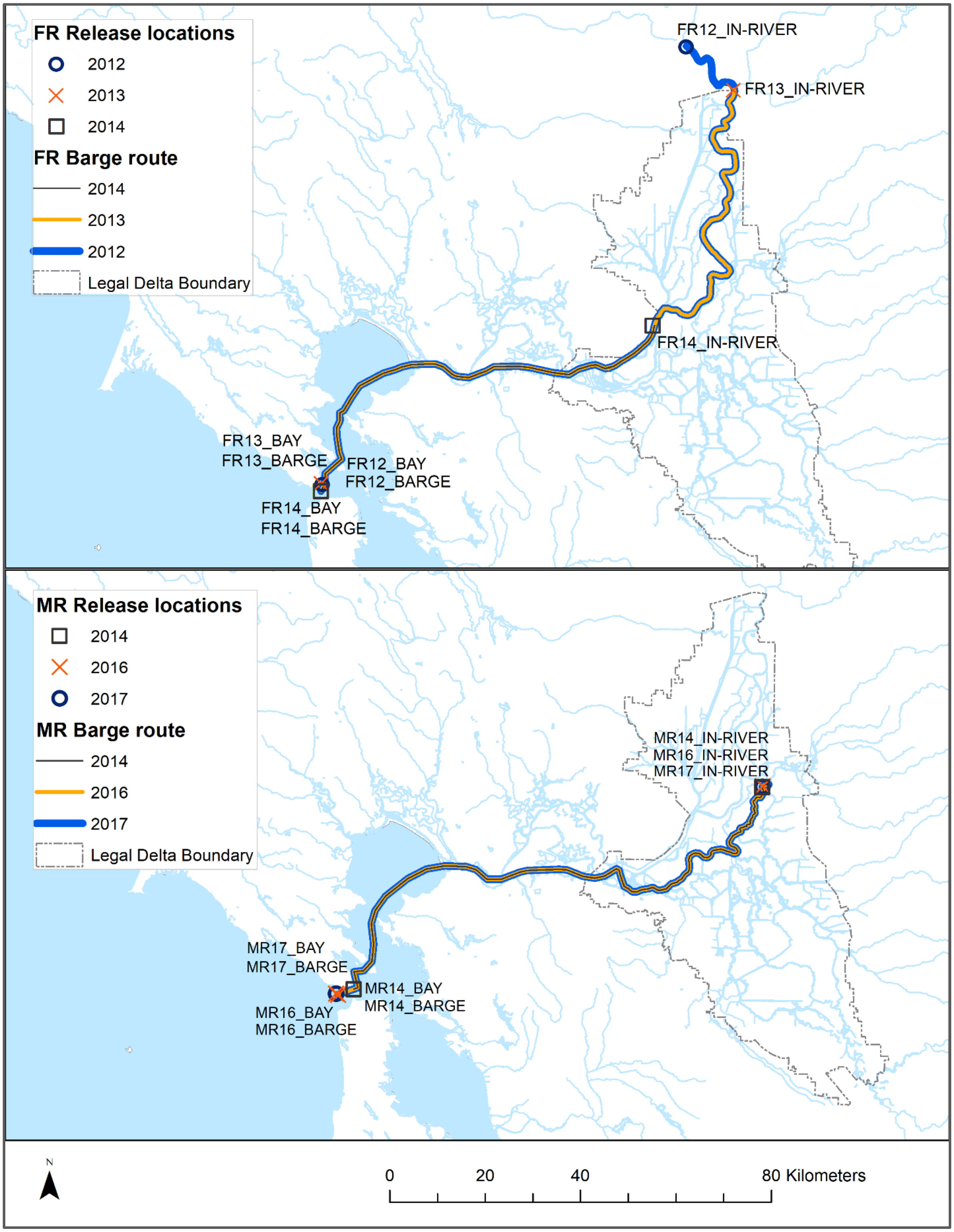

Figure 6. Barging routes and release locations for Feather River (FR) and Mokelumne River (MR) release groups.

between release groups, ranging from 97.4% to 99.8%. There was no retention check for group FR14_BAY (CWT code 06090) and the tag rate was assumed to be 100%. Estimated losses of salmon during transport and release varied among release groups and release years. The release groups of barged salmon in 2012 and 2013 (FR12_BARGE, FR13_BARGE) had the highest estimated losses of salmon during transport and release. The total number of live, tagged salmon released varied by 7.0% or less among release groups for the Feather River study.

Recoveries

Harvest

Standardized CWT recovery rates for ocean and inland harvest by Feather River release group are provided by Table 2. Commercial ocean harvest (ocean troll) recoveries from the Feather River releases were composed of age 2-4 salmon that were recovered between run years 2013 and 2017. Ocean troll recovery rates in CA and OR were similar between the 2012 in-river (FR12_IN-RIVER), Bay (FR12_BAY), and barge (FR12_BARGE) release groups, with the Bay release having the highest recovery rate of 886 (per 100,000 CWT salmon released). Ocean troll recovery rates were also similar between the 2014 in-river (FR14_IN-RIVER), Bay (FR14_BAY), and barge (FR14_BARGE) release groups. The 2014 Bay release group had the highest recovery rate of 149. There was a considerable difference between the ocean troll recovery rates of the 2013 Bay (FR13_BAY) and barge (FR13_BARGE) releases when compared to the 2013 in-river (FR13_IN-RIVER) release. The 2013 Bay and barge releases had standardized recovery rates that were roughly 60 times higher than the 2013 in-river release. Ocean troll recovery rates also varied by release year. Overall, the 2014 releases had lower recovery rates than the 2012 and 2013 releases.

Recreational ocean harvest (ocean sport) recoveries from the Feather River releases were composed of age 2-4 salmon that were recovered between run years 2013 and 2017. Ocean sport recovery rates in CA and OR were similar between the 2012 in-river, Bay, and barge release groups, with the barge release having the highest standardized recovery rate of 265 (per 100,000 CWT salmon released, Table 2). Ocean sport recovery rates were also similar between the 2014 in-river, Bay, and barge release groups. The 2014 in-river release group had the highest recovery rate of 66. Like the ocean troll recovery data, there was a considerable difference between the ocean sport recovery rates of the 2013 Bay and barge releases when compared to the 2013 in-river release. The 2013 Bay and barge releases had standardized recovery rates that were roughly 50-60 times higher than the 2013 in-river release. Ocean sport recovery rates also varied by release year. Overall, the 2014 releases had lower recovery rates than the 2012 and 2013 releases.

CCV inland harvest (freshwater sport) recoveries from the Feather River releases were composed of age 2-4 salmon that were recovered between run years 2013 and 2017. Freshwater sport recovery rates in the CCV were variable between the in-river, Bay, and barge release groups (Table 2). The 2012 Bay release group had a recovery rate nearly two times higher than the 2012 in-river and barge releases. In contrast, the 2013 barge release group had a recovery rate nearly two times higher than the 2013 Bay release and roughly 37 times higher than the 2013 in-river release group. The freshwater sport recovery rate was also nearly two

Table 2. Standardized commercial ocean (Ocean Troll), recreational ocean (Ocean Sport) and inland harvest (Freshwater Sport) recoveries for Feather River study release groups (Group ID), expressed as the number of CWT salmon recovered per 100,000 CWT salmon released.

Group ID	Ocean Troll (CA)	Ocean Troll (CA, OR)	Ocean Sport (CA)	Ocean Sport (CA, OR)	Freshwater Sport (CA)	Total
FR12_IN-RIVER	407	702	150	161	94	**958**
FR12_BAY	464	886	176	223	172	**1,281**
FR12_BARGE	350	668	245	265	103	**1,035**
FR13_IN-RIVER	10	19	9	9	13	**42**
FR13_BAY	1,049	1,230	546	549	257	**2,036**
FR13_BARGE	951	1,139	484	486	486	**2,111**
FR14_IN-RIVER	78	118	64	66	32	**216**
FR14_BAY	101	149	40	43	32	**224**
FR14_BARGE	72	105	45	45	59	**209**

times higher for the 2014 barge release group when compared to the 2014 Bay and in-river release groups. Freshwater sport recovery rates also varied by release year. Overall, the 2014 releases had lower recovery rates than the 2012 and 2013 releases.

CCV Escapement and Straying

Standardized CWT recovery rates for CCV escapement, by Feather River release group, are provided by Table 3. CCV escapement recoveries from the Feather River releases were composed of age 2-5 salmon that were recovered between run years 2013 and 2017. Escapement recoveries were similar between the 2012 in-river, Bay, and barge release groups, with the in-river release having the highest recovery rate of 577 (per 100,000 CWT salmon released). Escapement recoveries were also similar between the 2014 in-river, Bay, and barge release groups. The 2014 Bay release group had the highest recovery rate of 391. There was a considerable difference between the escapement recovery rates of the 2013 Bay and barge releases when compared to the 2013 in-river release. Standardized recovery rates for the 2013 Bay and barge releases were roughly 100 times higher than the recovery rates for the 2013 in-river release. Escapement recovery rates also varied by release year.

The distribution of escapement recoveries in the CCV, by Feather River release group, is depicted by Figure 7. Overall, the largest number of the recoveries were found in the Feather River hatchery basin (including the Yuba River). Most of the recoveries found outside of the Feather River hatchery basin were in the upper Sacramento River basin. Smaller numbers of strays were found in lower American River and at Nimbus hatchery. Stray recoveries in the San Joaquin basin and tributaries were infrequent and predominately captured at the MRH. CCV escapement recoveries for the 2012 and 2013 in-river releases were largely concentrated in the

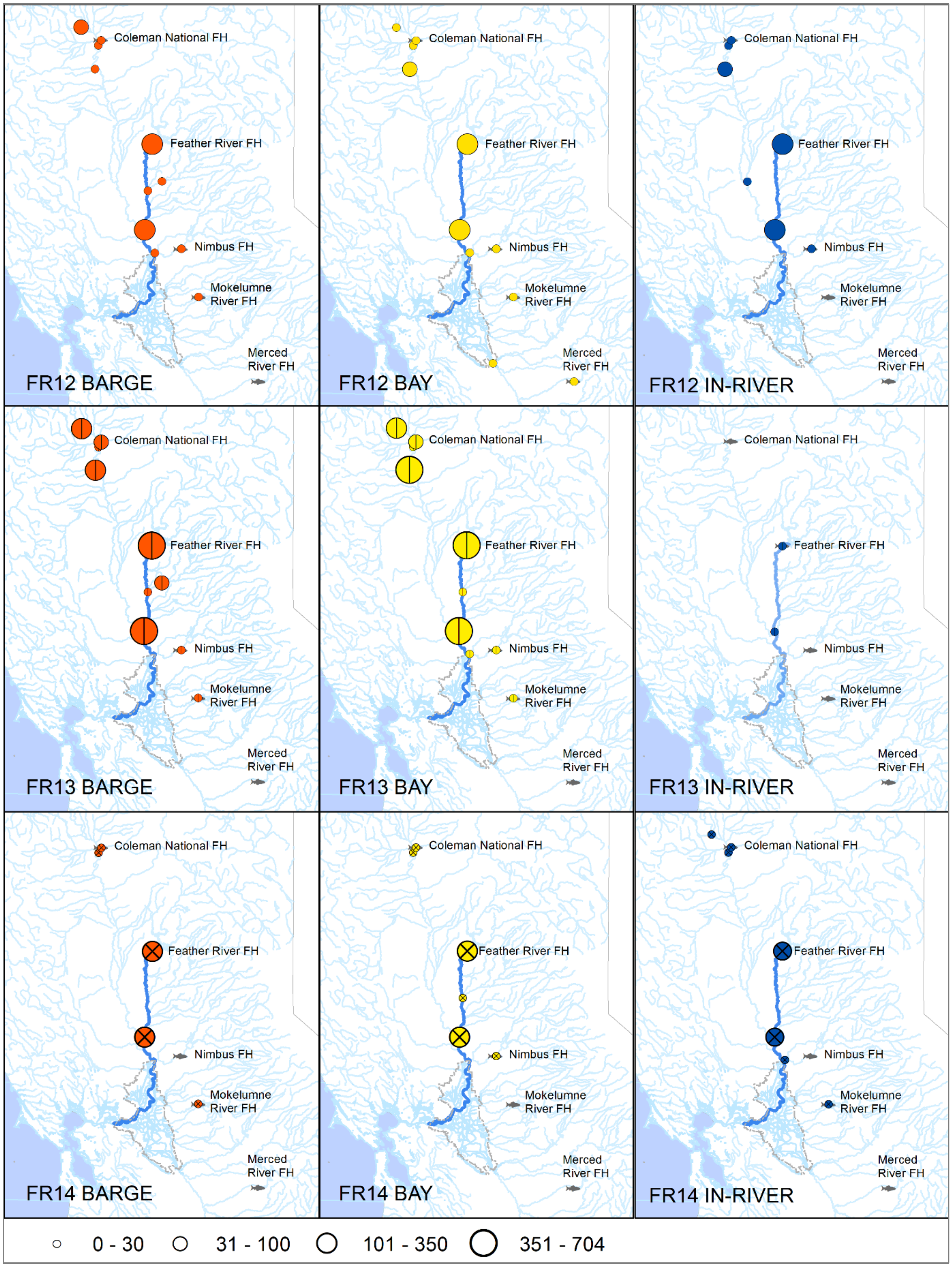

Figure 7. Distribution of CCV escapement CWT recoveries for Feather River (FR) release groups. The range of recoveries is represented by the size of the bubble, with higher ranges having larger bubbles.

Table 3. Standardized CCV escapement recovery rates (expressed as the number of CWT salmon recovered per 100,000 CWT salmon released) and CCV stray proportions for Feather River study release groups (Group ID).

Group ID	CCV Escapement	CCV Stray proportion
FR12_IN-RIVER	577	10.1%
FR12_BAY	448	28.5%
FR12_BARGE	536	19.7%
FR13_IN-RIVER	18	0.0%
FR13_BAY	1,710	35.8%
FR13_BARGE	2,012	27.7%
FR14_IN-RIVER	347	3.7%
FR14_BAY	391	2.2%
FR14_BARGE	354	0.6%

Feather River hatchery basin. In comparison, escapement recoveries for the 2012 and 2013 Bay and barge releases were more widely distributed in the CCV with a substantial number located in the upper Sacramento River basin. The distribution of escapement recoveries for all three of the 2014 release groups (in-river, Bay, and barge) was similar and largely concentrated in the Feather River hatchery basin.

Escapement stray proportions in the CCV for Feather River release groups are provided by Table 3. The 2012 in-river release group had the lowest CCV stray proportion (10.1%) when compared with stray proportions for the 2012 Bay and barge releases (28.5% and 19.7%, respectively). Results were similar for the 2013 releases, with the 2013 in-river release group having the lowest CCV stray proportion (0.0%), followed the 2013 barge release group (27.7%), and the 2013 Bay release group (35.8%). However, it is worth noting that the stray proportion for the 2013 in-river release (0%) was based on very few CCV escapement recoveries. CCV stray proportions for the 2014 releases were very low. The 2014 barge release group had the lowest CCV stray proportion of 0.6%, followed by the 2014 Bay release group (2.2%), and the 2014 in-river release group (3.7%).

Mokelumne River

Water Quality, Flow, and River Stage

During all three release years (2014, 2016, and 2017), water quality parameters were collected on a continual basis, including times when the barge was anchored in the Bay.

Water temperatures were similar between the barge holding tank and outside of the tank along the barging route in 2014, 2016, and 2017 (Figure 8). However, water temperatures varied between release years in the barge tank. Water temperatures were higher in 2014, ranging between 14.5 and 19.8°C and averaging 17.8°C. In 2016, water temperature ranged between 13.5 and 18.3°C and averaged 16.7°C. In 2017, water temperature ranged between 13.2 and

18.1°C and averaged 15.8°C.

Dissolved oxygen levels were lower in the barge holding tank when compared to conditions outside of the tank along the barging route in 2014 and 2017 (Figure 8). Dissolved oxygen levels intermittently dropped between 1-3 mg/L lower in the barge tank than in the Bay-Delta in 2014, were similar in the barge holding tank when compared to conditions outside of the tank in 2016 and ranged between 1-2 mg/L lower in the barge tank than in the Bay-Delta in 2017. Dissolved oxygen levels also varied between release years in the barge tank. In 2014, dissolved oxygen ranged between 5.79 and 9.16 mg/L and averaged 7.73 mg/L. In 2016 and 2017, dissolved oxygen levels were lower, ranging between 5.51 and 8.67 mg/L and averaging 6.53 mg/L in 2016 and ranging between 6.01 and 8.43 mg/L and averaging 7.15 mg/L in 2017.

Salinity and conductivity were similar between the barge holding tank and outside of the tank along the barging route during each release year (Figure 9). However, salinity varied between release years in the barge tank. In 2014, average salinity in the barge tank was 13.8 ppt. In 2016 and 2017 salinity was lower in the barge tank, averaging 6.5 and 3.5 ppt, respectively. During each release year, pH was lower in the barge holding tank when compared to conditions outside of the tank (Figure 9). In the barge tank, pH also varied between release years and was generally lower in 2017 when compared to 2014 and 2016.

River stage and flow were slightly higher at the NMR gauge during the 2016 barging event when compared with the 2014 barging event (Figure 10). Negative flows were an indicator of an incoming tide, while positive flows were an indicator of an outgoing tide. During the first four hours of the 2014 and 2016 barging events, the river stage at NMR ranged between 6.4 and 6.7 m (21-22 ft). Flow ranged between -111 and 110 cms (-3,910 and 3,880 cfs) at NMR in 2014. In 2016, flow ranged between -135 and 142 cms (-4,780 and 5,010 cfs) at NMR. At the MOK gauge, river stage and flow were higher during the 2017 barging event when compared with the 2014 and 2016 barging events (Figure 10). During the first four hours of the 2017 barging event, river stage at MOK ranged between 5.1 and 5.6 m (16.7-18.4 ft). During the first four hours of the 2014 and 2016 barging events, river stage at MOK ranged between 4.9 and 5.4 m (16.1-17.7 ft). Flow ranged between -343 and 382 cms (-12,100 and 13,500 cfs) at MOK in 2014. In 2016, flow ranged between -345 and 430 cms (-12,200 and 15,200 cfs) at MOK and in 2017 flow ranged between -116 and 694 cms (-4,090 and 24,500 cfs) at MOK.

Barge Route, Travel Time, Distance, and Speed

During all three barging events, the maximum upstream extent of the route was Miller's Ferry Bridge on the North Fork of the Mokelumne River. The river stage at NMR and MOK exceeded 4.9 m (16.1 ft) at the beginning of transport during the three barging events in 2014, 2016, and 2017.

In 2014, the barge route covered approximately 138 km (86 mi.) through Bay-Delta and took place over 26 hours including an overnight stop in the Bay (Benicia). The average speed of the barge was 3.3 km/h (5.3 mph) including all stopping time. The maximum speed of the barge

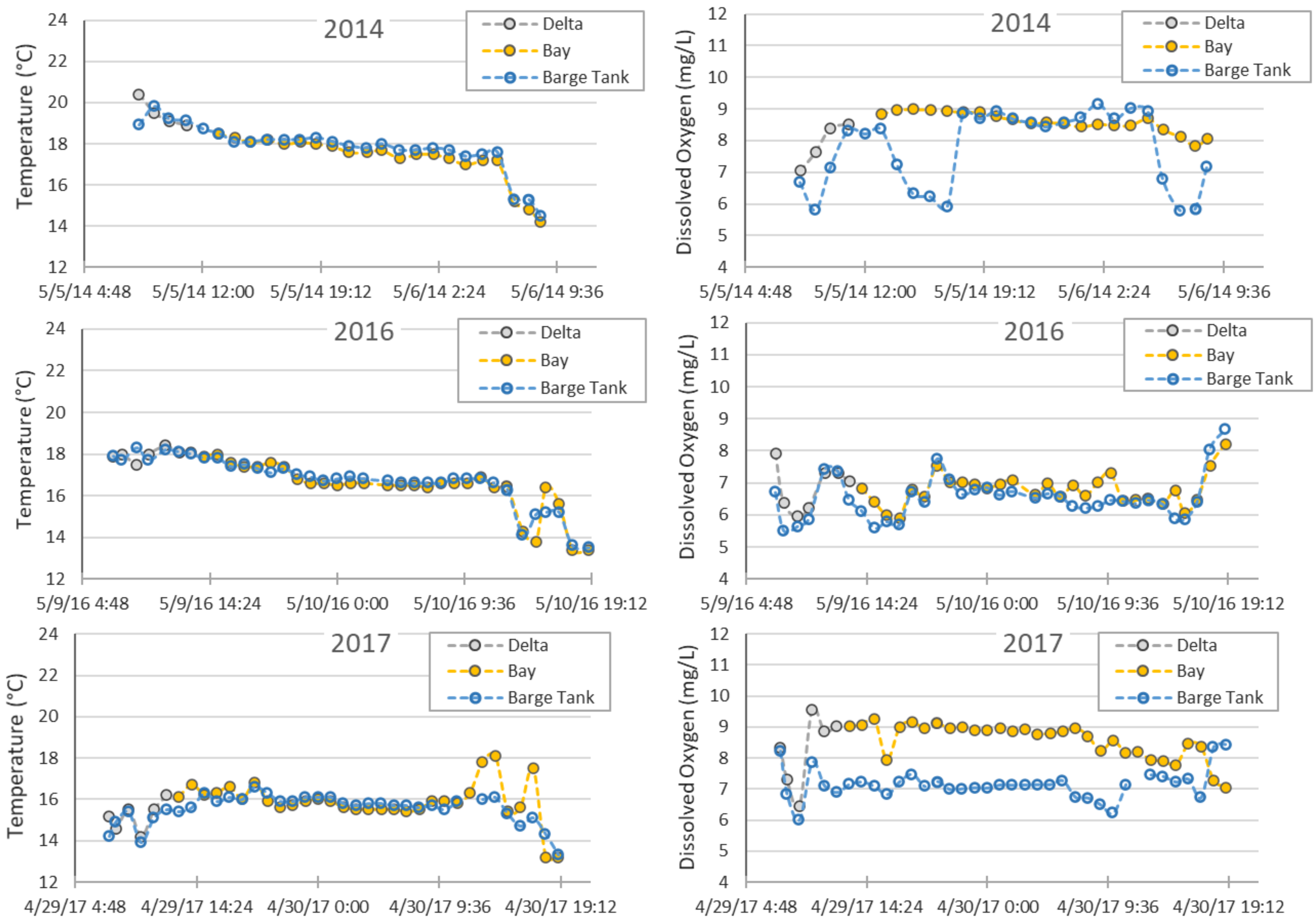

Figure 8. A comparison of water temperatures and dissolved oxygen levels by release year and between the barge tank and the water samples taken outside of the tank (Delta and Bay) along the barging route for the Mokelumne River pilot study.

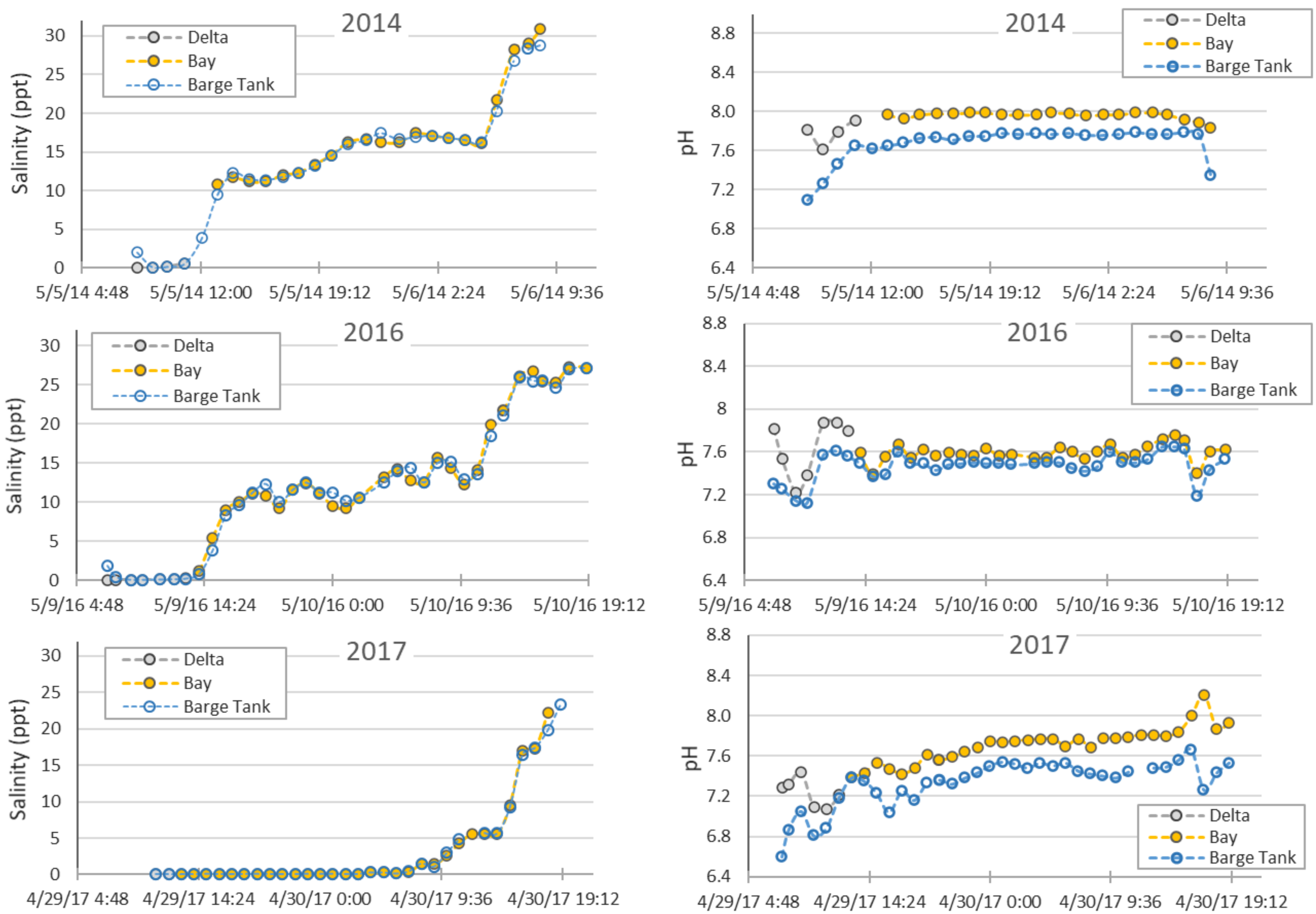

Figure 9. A comparison of salinity and pH levels by release year and between the barge tank and the water samples taken outside of the tank (Delta and Bay) along the barging route for the Mokelumne River pilot study.

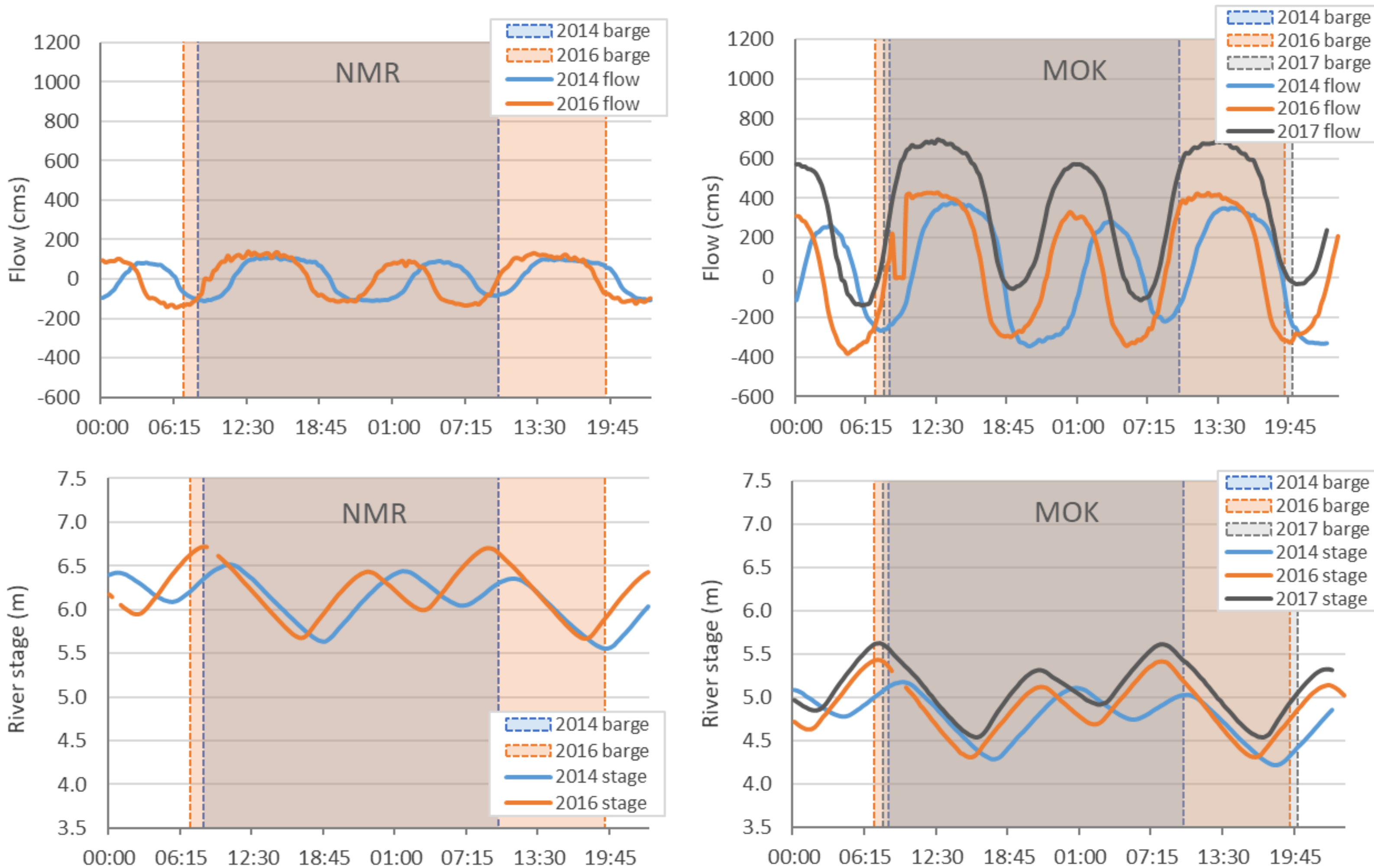

Figure 10. River flow (top) and stage (bottom) at the North Fork Mokelumne River gauge (NMR) and the Mokelumne River gauge (MOK) during the 2014, 2016, and 2017 barging events for the Mokelumne River study. Data during the 2017 barging event were not available at the NMR gauge.

over any given segment along the route was 12.4 km/h (20.0 mph) and the minimum speed over any moving segment was 4.0 km/h (6.4 mph).

In 2016, the barge route was nearly identical to the 2014 route and covered 137 km (85 mi.) through Bay-Delta and took place over 36.6 hours including an overnight stop in the Bay (Benicia). The average speed of the barge was 2.4 km/h (3.8 mph) including all stopping time. The maximum speed of the barge over any given segment along the route was 10.5 km/h (16.9 mph) and the minimum speed over any moving segment was 1.4 km/h (2.3 mph).

In 2017, the barge route was comparable to the previous courses for the Mokelumne River study and covered 137 km (85 mi.), starting in the Delta. Barging took place over 36.9 hours including an overnight stop in the Bay (Benicia). The average speed of the barge was 2.3 km/h (3.7 mph) including all stopping time. The maximum speed of the barge over any given segment along the route was 11.2 km/h (18.1 mph) and the minimum speed over any moving segment was 1.1 km/h (1.8 mph).

Fish Releases

A summary of information associated with each release group during the Mokelumne River study is provided by Table 4. Labels used to identify each release group are established in the column named Group ID. The average weight of the salmon in each release group ranged between 8.7 and 10.1 grams per fish. The release locations for each release group type (in-river, Bay, barge) were consistent between years (Table 4, Figure 6). Net pens were used for the in-river release groups during all three release years (2014, 2016, 2017).

The number of salmon in each release group prior to transport was near 100,000 and deviated between release groups by 1.2% or less. Tag (CWT and adipose fin-clip) rates were also similar between release groups, ranging from 96.5% to 100%. Estimated losses of salmon during transport and release were very low or zero for all release groups. The total number of live, tagged salmon released varied by 4.4% or less between release groups for the Mokelumne River study.

Recoveries

Harvest

Standardized CWT recovery rates for ocean and inland harvest by Mokelumne River release group are provided by Table 5. Commercial ocean harvest (ocean troll) recoveries for Mokelumne River releases were composed of age 2-4 salmon that were recovered between run years 2015 and 2019. Recoveries from the 2017 Mokelumne River releases were only available for age 2 and age 3 fish. There was a considerable difference between the ocean troll recovery rates of the 2014 Bay (MR14_BAY) and barge (MR14_BARGE) releases when compared to the 2014 in-river (MR14_IN-RIVER) release. The 2014 Bay and barge releases had standardized recovery rates (326 and 361, respectively) that were roughly 65-72 times higher than the 2014 in-river release recovery rate (5). Ocean troll recovery rates were highest for the 2016 barge (MR16_BARGE) release group (936), when compared to the 2016 Bay (MR16_BAY) and in-river (MR16_IN-RIVER) release groups which had recovery rates of 709 and 41, respectively. Ocean

Table 4. A summary of Mokelumne River study release groups including physical, biological, and other information associated each group. MRH = Mokelumne River Hatchery, CS= Chinook salmon, tagged = CWT and adipose fin-clip.

Group ID	Tag code	Hatchery origin	Brood year	Species (run)	Ave. weight (g)	Release date	Release time	Release location	Net pens used?	Number of salmon before transport	Number of salmon tagged	Tag rate	Estimated losses during transport & release	Number of tagged live salmon released
MR14_IN-RIVER	060592	MRH	2013	CS (fall)	9.06	5/5/14	12:15	Mokelumne River, NF at Miller's Ferry	Yes	100,685	100,181	0.995	0	100,181
MR14_BAY	060570	MRH	2013	CS (fall)	9.44	5/6/14	9:40	Golden Gate Bridge	No	101,304	101,051	0.998	100	100,951
MR14_BARGE	060593	MRH	2013	CS (fall)	10.07	5/6/14	9:40	Golden Gate Bridge	No	101,680	101,426	0.998	100	101,326
MR16_IN-RIVER	060765	MRH	2015	CS (fall)	9.06	5/9/16	10:45	Mokelumne River, NF at Miller's Ferry	Yes	101,135	101,135	1.000	0	101,135
MR16_BAY	060764	MRH	2015	CS (fall)	9.06	5/10/16	19:10	Golden Gate Bridge	No	101,235	100,982	0.998	0	100,982
MR16_BARGE	060766	MRH	2015	CS (fall)	9.06	5/10/16	19:10	Golden Gate Bridge	No	100,865	100,613	0.998	0	100,613
MR17_IN-RIVER	060988	MRH	2016	CS (fall)	8.72	4/29/17	11:00	Mokelumne River, NF at Miller's Ferry	Yes	100,790	100,032	0.992	0	100,032
MR17_BAY	060987	MRH	2016	CS (fall)	8.72	4/30/17	19:35	Golden Gate Bridge	No	100,435	96,885	0.965	0	96,885
MR17_BARGE	060989	MRH	2016	CS (fall)	8.72	4/30/17	19:35	Golden Gate Bridge	No	100,467	98,203	0.977	0	98,203

Table 5. Standardized commercial ocean (Ocean Troll), recreational ocean (Ocean Sport) and inland harvest (Freshwater Sport) recovery rates for Mokelumne River study release groups (Group ID), expressed as the number of CWT salmon recovered per 100,000 CWT salmon released. Recovery rates where age 4 fish are not included are reported in italics. Recovery rates were not reported where only age 2 recovery data exist.

Group ID	Ocean Troll (CA)	Ocean Troll (CA, OR)	Ocean Sport (CA)	Ocean Sport (CA, OR)	Freshwater Sport (CA)	Total
MR14_IN-RIVER	5	**5**	0	**0**	**0**	**5**
MR14_BAY	173	**326**	206	**208**	**13**	**546**
MR14_BARGE	218	**361**	241	**243**	**144**	**747**
MR16_IN-RIVER	37	**41**	35	**35**	***34***	**110**
MR16_BAY	562	**709**	713	**736**	***100***	**1,545**
MR16_BARGE	759	**936**	707	**740**	***274***	**1,950**
MR17_IN-RIVER	*93*	***100***	*102*	***102***	not available	***202***
MR17_BAY	*324*	***341***	*205*	***211***	not available	***552***
MR17_BARGE	*303*	***333***	*266*	***296***	not available	***629***

troll recovery rates for the 2017 Bay (MR17_BAY) and barge (MR17_BARGE) releases were roughly three times higher than the recovery rate for the 2017 in-river release (MR17_IN-RIVER).

Recreational ocean harvest (ocean sport) recoveries from the Mokelumne River releases were composed of age 2-4 salmon that were recovered between run years 2015 and 2019. Recoveries from the 2017 Mokelumne River releases were only available for age 2 and age 3 fish. Ocean sport recovery rates in CA and OR were much higher for the 2014 Bay and barge release groups, when compared with the 2014 in-river release recovery rate (per 100,000 CWT salmon released, Table 5). There was also a considerable difference between the ocean sport recovery rates of the 2016 Bay and barge releases when compared to the 2016 in-river release. The 2016 Bay and barge releases had standardized recovery rates (736 and 740, respectively) that were roughly 21 times higher than the 2016 in-river release recovery rate (35). Ocean sport recovery rates were highest for the 2017 barge release group (296), when compared to the 2016 Bay and in-river release groups, which had recovery rates of 211 and 102, respectively.

CCV inland harvest (freshwater sport) recoveries from the Mokelumne River releases were composed of age 2-3 salmon that were recovered between run years 2015 and 2018. Recoveries from the 2017 Mokelumne River releases were only available for age 2 fish and excluded from analysis. Freshwater sport recovery rates in the CCV were variable between the in-river, Bay, and barge release groups (Table 5). Freshwater sport recovery rates were highest for the 2014 barge release group (144), when compared to the 2014 Bay and in-river release groups, which had recovery rates of 13 and 0, respectively. The 2016 barge release group also had a recovery rate (274) that was higher than the 2016 Bay and in-river releases (100 and 34, respectively).

CCV Escapement and Straying

Standardized CWT recovery rates for CCV escapement, by Mokelumne River release group, are provided by Table 6. CCV escapement recoveries from the Mokelumne River releases were composed of age 1-4 salmon that were recovered between run years 2014 and 2018. The single age 1 recovery was excluded from analysis. Recoveries from the 2016 Mokelumne River releases were only available for age 2 and age 3 fish. Recoveries from the 2017 Mokelumne River releases were only available for age 2 fish and excluded from analysis. CCV escapement recovery rates were highest for the 2014 barge release group (506), when compared to the 2014 Bay and in-river release groups, which had recovery rates of 171 and 8, respectively. The 2016 barge release group also had the highest CCV escapement recovery rate of 1,681 when compared to the recovery rates for the 2016 Bay and in-river releases (934 and 132, respectively).

The distribution of escapement recoveries in the CCV, by Mokelumne River release group, is depicted by Figure 11. Many of the recoveries found outside of the Mokelumne River hatchery basin were in the American River hatchery basin, the Stanislaus River, and the Merced River hatchery basin. Smaller numbers of stray recoveries were found in the Feather River hatchery basin, the Tuolumne River, and the upper Sacramento River basin. CCV escapement recoveries for the 2014 and 2016 in-river releases were largely concentrated in the Mokelumne River hatchery basin. In comparison, escapement recoveries for the 2014 and 2016 Bay and barge releases were more widely distributed in the CCV with a substantial number located in the American River hatchery basin and the Stanislaus River.

Table 6. Standardized CCV escapement recoveries (expressed as the number of CWT salmon recovered per 100,000 CWT salmon released) and CCV stray rates for Mokelumne River study release groups (Group ID). Age 4 fish are not included in recovery and stray rates that are reported in italics. Recovery and stray rates are reported as not available when only age 2 recovery data exist.

Group ID	CCV Escapement	CCV Stray proportion
MR14_IN-RIVER	8	0.0%
MR14_BAY	171	80.1%
MR14_BARGE	506	54.4%
MR16_IN-RIVER	*132*	*7.2%*
MR16_BAY	*934*	*49.9%*
MR16_BARGE	*1,681*	*41.5%*
MR17_IN-RIVER	not available	not available
MR17_BAY	not available	not available
MR17_BARGE	not available	not available

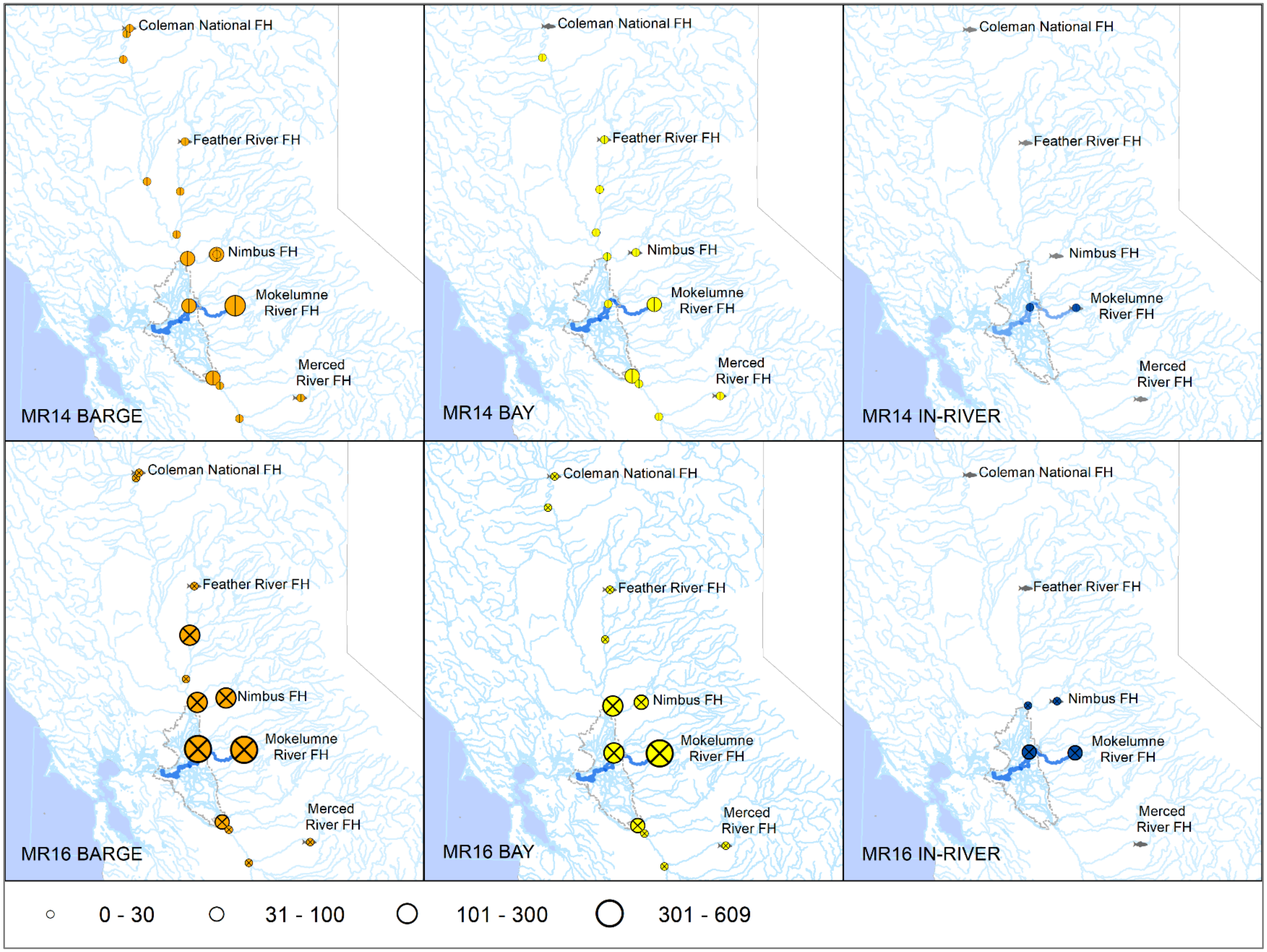

Figure 11. Distribution of CCV escapement CWT recoveries for Mokelumne River (MR) release groups. The range of recoveries is represented by the size of the bubble, with higher ranges having larger bubbles.

Escapement stray proportions in the CCV for Mokelumne River release groups are provided by Table 6. The 2014 in-river release group had the lowest CCV stray proportion (0%) when compared with stray proportions for the 2014 barge and Bay releases (54.4% and 80.1%, respectively). However, it is worth noting that the stray proportion for the 2014 in-river release (0%) was based on very few expanded CCV escapement recoveries (8). Results were similar for the 2016 releases, with the 2016 in-river release group having the lowest CCV stray proportion (7.2%), followed the 2016 barge release group (41.5%), and the 2016 Bay release group (49.9%).

Discussion

Feather River

Despite low flow conditions due to the extended drought in California (2012-2016), barging juvenile salmon from the Sacramento River through the Bay-Delta was feasible during all three release years (2012-2014) with some modifications to the study design. As the drought progressed, the barge loading and in-river release sites were moved farther downstream to accommodate barge travel, which requires the river stage to be 16 ft or higher. This resulted in a 2014 in-river release location in the Delta, a reduction in the 2014 barging route by nearly half of the total distance traveled in 2012, and a small reduction in overall barge travel time in 2014. In addition to flow reductions, water temperatures in the spring increased each release year in the lower Sacramento River as the drought persisted (CDEC 2020). During the first two years of the study Chinook salmon smolts were released in May, but in 2014 releases took place in early April to reduce mortalities due to warm water temperatures. It is possible that the early April releases occurred before the optimal time lag of 70 to 115 days after the spring transition date, which is a useful predictor of within-year variation in survival rates (Satterthwaite et al. 2014).

During all three release years, many of the water quality parameters measured (water temperature, salinity, and conductivity) were similar between the barge holding tank and outside of the tank along the barging route. However, water quality parameters were not similar between release years. In 2013, water temperatures were relatively high in the barge holding tank and averaged 20.1°C, while temperatures in 2012 and 2014 averaged 16.2°C. Consequently, the 2013 in-river and barge release groups may have been adversely affected by high water temperatures. In a laboratory study, juvenile Chinook salmon reared at 17-24°C experienced decreased growth rates, impaired smoltification, and increased predation vulnerability when compared with those reared at 13-16°C (Marine and Cech 2004).

Two of the water quality parameters measured, dissolved oxygen and pH, were lower in the barge holding tank when compared with the in-river and Bay conditions. The depressed levels of dissolved oxygen were likely due to the density and oxygen consumption of the fish in the holding tank and the water exchange rate between the tank and the river or Bay. Despite lower levels of dissolved oxygen in the holding tank, supplemental oxygen was effectively used to maintain levels at or above 5 mg/L throughout nearly all three release years. Dissolved oxygen concentrations below 5 mg/L may adversely affect growth, food conversion efficiency, and swimming performance of juvenile salmonids (Bjornn and Reiser 1991). Although pH levels were slightly lower in the barge holding tank compared to in-river and Bay conditions they were not considered highly acidic (<5.5), which can have a detrimental effect on eggs and juvenile salmonids (Carter 2008).

Each release year, the transport speed of the barge was faster than documented outmigration rates of Chinook salmon smolts through the Sacramento River and Delta. The overall transport speed of the barge ranged from 96 to 166 km/day including stopping time. Acoustic studies of wild salmon smolts have calculated mean outmigration rates of 33 km/day (2015) and 57 km/day (2016) in the Sacramento River and mean outmigration rates of 22.5 km/day (2016) in the Delta (Cordoleani et al. 2017). Barge speed likely resulted in reduced time for olfactory imprinting, which may play an important role in successful homing during adult migration. Previous experiments have shown that the time required for Sockeye salmon (*Oncorhynchus nerka*) and Coho salmon (*Oncorhynchus kisutch*) smolts to successfully imprint ranged from 10 days to 6 weeks (Hasler and Scholz 1983; Dittman et al. 1996; Yamamoto et al. 2010). A more recent study using Sockeye salmon demonstrated that smolts exposed to imprinting odors for 1 week or 6 weeks successfully imprinted, but smolts exposed to odors for 1 day did not (Havey et al. 2017).

There was some variation in the environmental and biological parameters associated with fish releases between and within years due to the drought, logistic constraints, and predation events. As mentioned previously, the study design was altered due to the drought causing changes in release dates and some release locations between years. In addition, fish size (weight) and release times also varied between years. The 2013 salmon smolts were roughly 4g heavier than the 2012 and 2014 smolts upon release. Some studies demonstrate a positive relationship between size of hatchery-origin salmon at release and survival, but it is generally one of many other factors associated with survival (Irvine et al. 2013, Satterthwaite et al. 2014).

Estimated losses of salmon during transport and upon release also varied between release years and within release years. In some cases, losses were more difficult to estimate than others because direct observation of loss was not possible. For example, the 2013 in-river release group was noted as weak and stressed when transferred from the transport truck to the net pens, but no obvious mortalities were noted upon release. However, the receiving water temperature in the Sacramento River was 21.8°C, which fell within the range of temperatures that increase predation vulnerability (Marine and Cech 2004). The 2013 barged study group was also noted as weak and stressed when transferred from the transport truck, but not released straightaway. Instead, mortalities were assessed upon release the following day and an estimated 6,000 mortalities were recorded based on the volume of dead salmon found in the bottom of the holding tank. The 2012 and 2013 Bay releases likely experienced significant mortality upon release, but direct observation was not possible. Losses due to predation beneath the water surface, trauma from release height, and abiotic factors within the harbor could not be determined.

Adult harvest and escapement recovery rates were variable for Feather River release groups within and between release years. Overall, release groups of juvenile fall-run Chinook salmon transported by barge had similar harvest and escapement recovery rates compared to Bay releases. The 2012 and 2014 releases of salmon transported by barge also had similar harvest and escapement recovery rates compared to in-river releases, but the 2013 barge releases had significantly higher harvest and escapement recovery rates than the 2013 in-river releases. Differences in smolt to adult survival between release years and within years has been documented in other studies and may be attributed to a variety of carryover effects such as in-river conditions, passage-type, Pacific decadal oscillation index, and Coastal upwelling index (Petrosky and Schaller 2010, Gosselin et al. 2017). The 2013 barge and Bay release groups were transported around or through the Delta in the absence of predators when water temperatures were exceptionally warm in mid-May. In contrast, the 2013 in-river release group encountered water temperatures ranging from 20-22.7°C through a long stretch of the Delta after already being noted as weak and stressed when transferred from the transport truck. In 2013, it is possible that release location and transport method played an important role in smolt to adult survival between the release groups, as previous studies have concluded that predation risk in the South Delta is strongly influenced by water temperature (Michel et al. 2019).

Escapement stray rates were also variable for Feather River release groups within and between release years. The 2012 and 2013 releases of Chinook salmon transported by barge had adult stray rates that were 8-9% lower than Bay releases, but stray rates that were 10% and 28% higher than in-river releases. It is worth noting that the 2013 stray rate of 0% for the in-river release group was based on few recoveries, which may have underestimated the value. These results were consistent with other studies in the Pacific Northwest, which demonstrate that barged salmon stray at higher rates when compared with in-river control groups (Keefer et al. 2008). Hatchery practices such as outplanting and transportation can interrupt sequential imprinting of juvenile salmon, leading to higher adult stray rates (Keefer and Caudill 2014). It is possible that barge transport disrupted imprinting by changing the natural outmigration speed and behavior of juvenile salmon, resulting in adult stray rates that were higher than in-river releases.

Interestingly, the adult stray rates of all three 2014 release groups were similar and ranged between 0.6 and 3.7%. These rates are considered low when compared to previous releases of Feather River hatchery salmon in the Bay (Palmer-Zwahlen et al. 2018, Palmer-Zwahlen et al. 2019a, Palmer-Zwahlen et al. 2019b, Palmer-Zwahlen and Kormos 2020). The Sacramento mainstem and Feather River fall flows were low in 2014 and 2015, but higher in 2016 (CDEC 2020). The return years of age-3 salmon from the 2012 and 2013 releases were 2014 and 2015, years when fall flows were low due to drought. In contrast, the return year of age-3 salmon from the 2014 releases was 2016, when fall flows were higher. Stray rates may also be influenced by the magnitude of the fall flows, as some studies demonstrate that importance of the magnitude of fall flows on homing success of adult Chinook salmon (Marston et al. 2012).

Mokelumne River

Barging juvenile salmon from the Mokelumne River through the Bay-Delta was feasible during all three release years (2014, 2016, 2017) following the proposed study design. Like the Feather River study, many of the water quality parameters measured (water temperature, salinity, and conductivity) were similar between the barge holding tank and outside of the tank along the barging route. However, dissolved oxygen and pH, were lower in the barge holding tank when compared with the in-river and Bay conditions. Lower levels of dissolved oxygen were likely due to the density and oxygen consumption of the fish in the holding tank and the water exchange rate between the tank and the river or Bay. But supplemental oxygen was effectively used to maintain levels at or above 5.5 mg/L. Dissolved oxygen and pH never fell below levels considered detrimental to growth, behavior, or food conversion efficiency (Bjornn and Reiser 1991, Carter 2008).

During each release year, the transport speed of the barge was faster than documented outmigration rates of Chinook salmon smolts through the Delta and Bay. The overall transport speed of the barge ranged from 89 to 127 km/day including stopping time. Acoustic studies of Chinook salmon smolts have calculated mean outmigration rates of 22.5 km/day (2016) in the Delta (Cordoleani et al. 2017) and mean outmigration rates ranging between 8.5 and 16.7 km/day (2007-2009) through the Delta and Bay (Michel et al. 2012). Like the Feather River portion of the study, barge speed likely resulted in reduced time for olfactory imprinting, which plays an important role in successful homing during adult migration (Hasler and Scholz 1983; Dittman et al. 1996; Yamamoto et al. 2010).

Adult harvest and escapement recovery rates were variable for Mokelumne River release groups within and between release years. Overall, release groups of juvenile fall-run Chinook salmon transported by barge had substantially higher harvest and escapement recovery rates compared to in-river releases. Barged releases also had slightly higher harvest recovery rates than Bay releases and considerably higher escapement recovery rates than Bay releases. The differences in smolt to adult survival between release years may have been largely due to carryover effects in the marine environment like Pacific decadal oscillation index and Coastal upwelling index, however in-river conditions, and passage-type most likely contributed to the differences in smolt to adult survival between barged and in-river releases. Mokelumne origin juvenile salmon must migrate downstream through the Central Delta, which is impacted by Central Valley and State Water Project operations and the management of the Delta Cross Channel. Previous studies have documented lower route specific survival of juvenile Chinook salmon through portions of the Central Delta when compared to the Sacramento River (Perry et al. 2010). Other studies have shown that the estimated survival of smolts through the San Joaquin Delta is considerably low when compared to other large West Coast rivers (Buchanan et al. 2013).

Escapement stray rates were also variable for Mokelumne River release groups within and among release years. The 2014 and 2016 releases of Chinook salmon transported by barge had adult stray rates that were 26% and 8% lower than Bay releases, but stray rates that were 54% and 34% higher than in-river releases. However, the 2014 stray rate of 0% for the in-river release group was based on few recoveries, which may have underestimated the value. These results were consistent with the Feather River study and other studies in the Pacific Northwest, which demonstrate that barged salmon stray at higher rates when compared with in-river control groups (Keefer et al. 2008). Like the Feather River study, barge transport may have disrupted imprinting by changing the natural outmigration speed and behavior of juvenile salmon. The complexity of the Sacramento-San Joaquin River Delta, operation of Central Valley and State Water Projects, and the Delta Cross Channel may have also contributed to the variation in adult stray rates between and within years. As Mokelumne origin adult salmon return from the ocean, management of the Delta Cross Channel Gate may influence adult straying into the Sacramento River system.

Management Implications

The pilot study demonstrated that barging juvenile salmon through portions of the Mokelumne River and Sacramento River outmigration routes is feasible on a small scale. The number of fall-run Chinook salmon barged during each release year accounted for roughly 0.3% of the total number of fall-run Chinook salmon produced annually as mitigation and enhancement fish. The coordination, logistics, and cost to barge a small proportion of the total production was substantial. If resource managers consider boat-based transport as a release strategy in the future, a larger analysis of resource needs, costs, and benefits would be required. A hatchery enhancement program of pink salmon in Alaska contributed to an order of magnitude increase in catch since the 1960s, but the benefits were considerably overestimated when accounting for reduced wild stock productivity and the costs of the hatchery program (Amoroso et al. 2017).

Overall, the findings of this study indicated that barging salmon to the Bay or releasing salmon directly in the Bay improved adult harvest rates when compared to in-river releases, particularly in the Mokelumne River system. Barged salmon also had lower adult stray rates when compared with paired groups released in the Bay. However, the results were tempered by the increased straying rates of barged releases when compared to in-river releases. Although the adult stray rates of barged salmon were lower than Bay releases, the size of a reduction needed to provide a population level benefit remains unknown.

If future barging studies are pursued, it will be important to determine if the logistics and cost of an expanded barging program are prohibitive. Finding a vessel(s) that can transport large groups of hatchery fall-run Chinook may be difficult. In addition, large groups of barged salmon would require adequate water circulation, aerators, and oxygen tanks to keep fish in good condition. It will also be important to consider the potential for transmission of pathogens in the barging environment (Van Gaest et al. 2011) and barge effects on the auditory function of salmon (Halvorsen et al. 2009). The overall travel time and speed of the barge should also be evaluated as it relates to mimicking juvenile outmigration rates yet keeping fish in good condition. Future studies should also address deteriorating water quality parameters, timing of releases, and varying flow conditions over multiple years. Finally, other strategies to improve adult survival and straying of naturally produced and hatchery origin salmon should also continue to be evaluated, such as adaptively managing Delta Cross Channel and pumping operations, improving river flows during critical migration periods, and habitat restoration activities.

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Appendices

Appendix A1. Estimated distances and travel times for barging juvenile salmon through the Feather River outmigration route.

Reach Description	Approximate distance between locations (miles)	Travel time between bridges at an average speed of 5 mph (hours)
I-5 Bridge to Tower Bridge	12.3	2.5
Tower Bridge to Freeport	14.0	2.8
Freeport to Paintersville	12.7	2.5
Paintersville to Walnut Grove	6.3	1.3
Walnut Grove to Isleton	7.9	1.6
Isleton to Rio Vista	6.2	1.2
Rio Vista Bridge to Benicia Bridge	28.6	5.7
Benicia Bridge to Carquinez Bridge	6.3	1.3
Carquinez Bridge to Fort Baker	24.8	5.0
Total	**119.0**	**23.8**

Appendix A2. Estimated distances and travel times for barging juvenile salmon through the Mokelumne River outmigration route.

Reach Description	Approximate distance between locations (miles)	Travel time between bridges at an average speed of 5 mph (hours)
Miller's Ferry Bridge to Highway 12 Bridge	9.7	1.9
Highway 12 Bridge to Antioch Bridge	15.7	3.1
Antioch Bridge to Sacramento River Confluence at Pittsburg	7.8	1.6
Confluence at Pittsburg to Benicia Bridge	15.0	3.0
Benicia Bridge to Richmond Bridge	22.3	4.5
Richmond Bridge to Romberg Center	8.1	1.6
Romberg Center to Golden Gate	6.8	1.4
Total	**85.3**	**17.1**

Appendix B. A summary of notes taken before, during, and/or after each release for the Feather River barge study.

Group ID	Tag code	Notes	Estimated Mortalities
FR12_IN-RIVER	069502	Fish were released directly into current about 100 feet from shore. The decision was made to not use the pontoon-based net-pen. No predation was noted during release and fish appeared to orient themselves and distribute rapidly in the current.	0
FR12_BAY	069504	The decision was made to utilize the pier as opposed to releasing fish from the access road at Fort Baker. As with the in-river release the decision was made to not use the pontoon-based net-pen during the release. Some avian predation (gulls and cormorants) occurred on stunned fish. Overall predation was minimal (≈150 fish as estimated by the number of birds and dives each took) due to rapid release from hatchery truck.	150
FR12_BARGE	068685	Fish seem very well acclimated and dispersed immediately upon release. It was noted as the holding tank was drained that many fish (≈2000 fish) had escaped behind the front false bulkhead in the holding tank through a small whole at the bottom of the false bulkhead. Some of these fish were recovered and released but some were pulled into the pumping system while draining the tank and were noted as mortalities.	1,000
FR13_IN-RIVER	060471	Fish out of transport truck were weak and stressed. Some fish were noted as stuck in the release pipe and some of these fish fell on the dock when pipe was being disassembled. There may have been too many fish in the transport truck for the volume of water and they may have been in the tank for too long. Fish were released from the acclimation pen. Fish appeared to be in good condition with no obvious mortalities noted.	0
FR13_BAY	060472	Two trucks were taken to avoid any potential risk of overcrowding fish in one tanker as observed with the in-river release group. It was concluded there were no options for loading fish into the holding tank for acclimation. Some avian predation noted.	250
FR13_BARGE	060473	Fish out of transport truck were weak and stressed. Some fish were noted as stuck in the release pipe and some of these fish fell on the dock when pipe was being disassembled. There may have been too many fish in the transport truck for the volume of water and they may have been in the tank for too long. When processing mortalities sitting at bottom of holding tank from previous day, a volumetric estimate of 6,000 mortalities was recorded.	6,000
FR14_IN-RIVER	060572	Net pens towed out to channel and released at 13:45. Fish looked excellent, minor losses less than 1,000.	500
FR14_BAY	060525	Transferred fish to Merva W at 10:10. Started releasing under the Golden Gate at 11:45 the following day. Finished the release at 12:30. Minor fish losses observed (less than 1,000).	250
FR14_BARGE	060524	Started releasing under the Golden Gate at 11:45. Finished the release at 12:30. Minor fish losses observed (less than 1,000). Bird predation far less than previous years.	250

Appendix C. A summary of notes taken before, during, and/or after each release for the Mokelumne River barge study.

Group ID	Tag code	Notes	Estimated Mortalities
MR14_IN-RIVER	60592	Truck transferred fish into net pen at 10:45 without incident. Fish released at 12:15 in good condition with no losses observed.	0
MR14_BAY	60570	Start releasing fish under the Golden Gate at 9:40 and finished at 10:30. Minor fish losses observed (less than 200). Minor bird predation, but far less than previous years.	100
MR14_BARGE	60593	Start releasing fish under the Golden Gate at 9:40 and finished at 10:30. Minor fish losses observed (less than 200). Minor bird predation, but far less than previous years.	100
MR16_IN-RIVER	60765	Fish transferred from truck to net pen at 8:45 without incident. Fish released from net pen at 10:45 with no losses recorded.	0
MR16_BAY	60764	Fish transferred fish from truck to Merva W in Sausalito. All fish released from Merva W at Golden Gate Bridge successfully. No losses were recorded.	0
MR16_BARGE	60766	Fish transferred from truck to barge at Miller's Ferry Bridge. All fish released from Merva W at Golden Gate Bridge successfully. No losses were recorded.	0
MR17_IN-RIVER	60988	Fish transferred from truck to net pen at 9:00 without incident. Fish released from net pen at 11:00 with no losses recorded.	0
MR17_BAY	60987	Fish transferred fish from truck to Merva W in Sausalito. All fish released from Merva W at Golden Gate Bridge successfully. No losses were recorded.	0
MR17_BARGE	60989	Fish transferred from truck to barge at Miller's Ferry Bridge. All fish released from Merva W at Golden Gate Bridge successfully. No losses were recorded.	0

Photo Appendix

Picture 1. CDFW transport truck unloading salmon into the barge (*Merva W*) holding tank.

Picture 2. The *Merva W,* a commercial squid boat used to barge salmon for the study, and its entire displacement hull seen outside of the water.

Picture 3. The release of salmon from the transport truck to the barge holding tank through metal pipe and 8-inch flex tubing.

Picture 4. The *Merva W* docked just upstream of Miller's Ferry bridge on the North Fork of the Mokelumne River.

Picture 5. CDFW transport truck unloading salmon into an acclimation pen at the Broderick boat ramp on the Sacramento River.

Picture 6. The Fort Baker pier and vicinity, the general location where many of the salmon from the Bay release groups were transferred from the CDFW trucks to the barge or directly released.