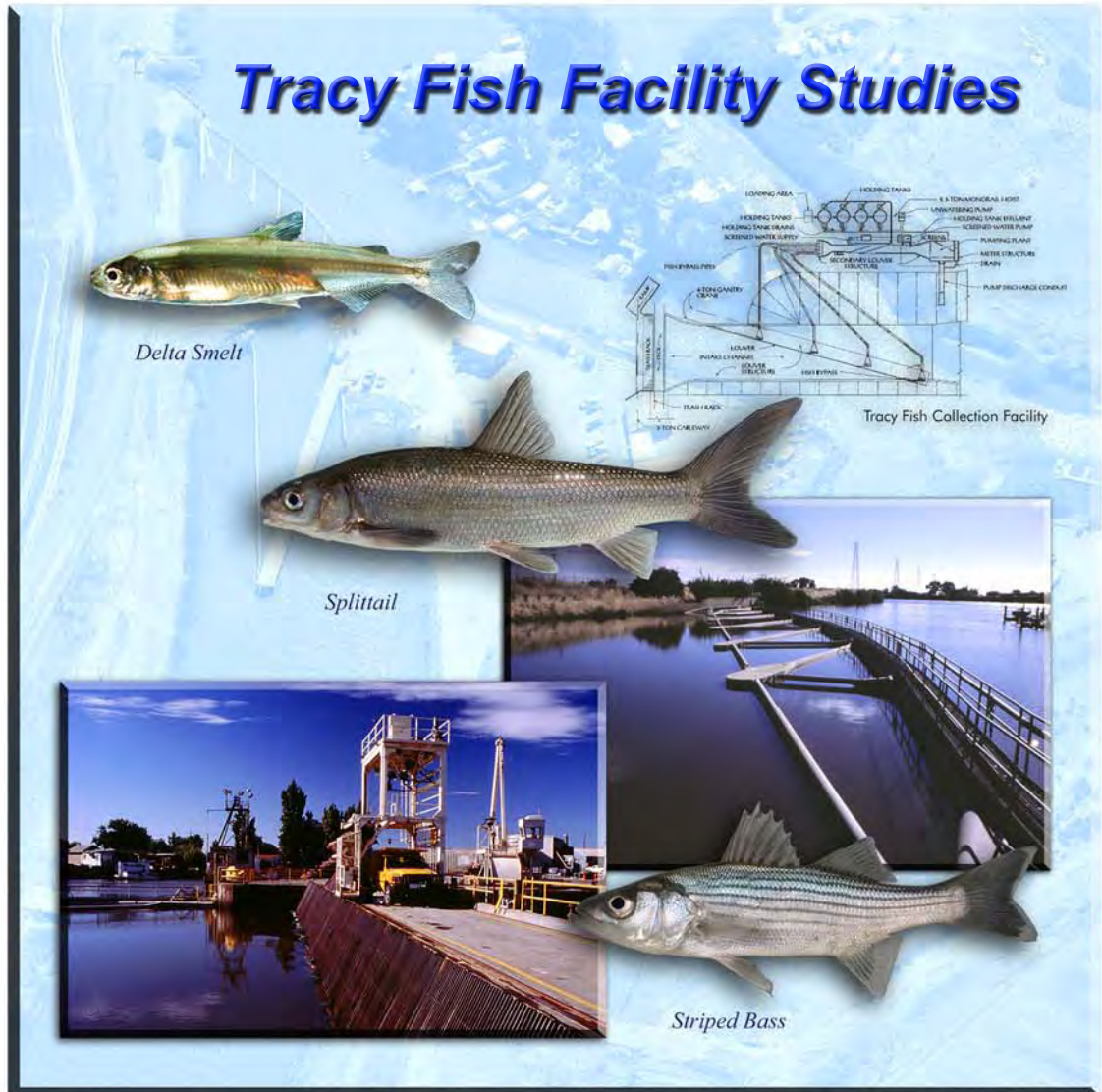


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Managing Water in the West



Changes in Water Quality During Fish-Hauling Operations at the Tracy Fish Collection Facility

Tracy Technical Bulletin 2008-2

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Tracy Fish Facility Studies California

Changes in Water Quality During Fish-Hauling Operations at the Tracy Fish Collection Facility

Tracy Technical Bulletin 2008-2

by

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October 2008

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TABLE OF CONTENTS

| | <i>Page</i> |
|-------------------------------------|-------------|
| Abstract | iv |
| Introduction | 1 |
| Methods | 5 |
| Hauling Truck Water Quality | 5 |
| Truck Water Loss..... | 5 |
| Oxygen Production Rates | 6 |
| Fish Densities..... | 6 |
| Results and Discussion | 6 |
| Recommendations | 10 |
| Acknowledgments | 11 |
| References | 11 |

Tables

| <i>Tables</i> | <i>Page</i> |
|---|-------------|
| 1 Percentage of species transported, mean number, and density of fish transported. | 8 |
| 2 Maximum and minimum water quality levels observed in the Tracy Fish Collection Facility fish-hauling truck and at the Emmaton Release Site. Water quality levels were monitored between June 2005 and June 2006. | 8 |
| 3 Changes in water temperature (ΔT) experienced by fish during the Tracy Fish Collection Facility loading, hauling, and release procedures..... | 10 |

Figures

| <i>Figures</i> | <i>Page</i> |
|---|-------------|
| 1 Map of the Sacramento-San Joaquin Delta depicting the Tracy Fish Collection Facility, Bill Jones Pumping Plant, and Emmaton Fish Release Site..... | 2 |
| 2 Side view and top view of the Tracy Fish Collection Facility holding tanks used to support fish after collection and prior to hauling. | 3 |
| 3 The Tracy Fish Collection Facility fish-hauling truck. | 4 |
| 4 The Tracy Fish Collection Facility fish haul-out bucket..... | 4 |
| 5 Tracy Fish Collection Facility fish-hauling truck tank water volume as a function of water depth below tank surface; measured as depth from top of tank to water surface..... | 7 |

ABSTRACT

A short-term pilot study was conducted between June 2005 and 2006 to measure the effects of fish density on important water quality parameters during fish transport in fish-hauling trucks from the U.S. Bureau of Reclamation's Tracy Fish Collection Facility (TFCF; Byron, California). Fish density (0.3–64.5 grams [g] of fish/liter [L]) and water quality parameters of concern during the transport of fish generally remained within acceptable ranges over the duration of our study. Ranges of temperature, dissolved oxygen (DO), free hydrogen ion activity (pH), total ammonia nitrogen (TAN), and percent total gas saturation (TGS) were 15.2–25.3 degrees Celsius (°C), 5.8–>19.0 milligrams (mg) oxygen/L, 6.5–7.9 standard pH units, 0.2–2.0 mg TAN/L, and 101–106% TSG, respectively. On one occasion, fish transport densities were above recommended (64.5 g of fish/L), and resulted in elevated carbon dioxide (CO₂) levels of 20 mg/L. However, the efficiency of the transport truck oxygenation system maintained DO levels above saturation, and therefore counteracted the possible negative effects of mild hypercapnia. Data collected from this study support the continuation or redevelopment of a large-scale TFCF fish-hauling truck water quality monitoring program.

INTRODUCTION

Water quality can affect the success of fish transportation; adverse conditions impair important physiological processes, ultimately affecting health, and reducing fish performance and survival (Moyle and Cech, 2004; Portz *et al.*, 2006). Water quality at the onset of transportation is a necessary consideration; it is easy to obtain, provides baseline levels, and is an indication of how much change is acceptable before individual parameters reach unhealthy or critical levels. However, water quality changes throughout transport, and the subsequent levels at the end of transport should be the primary consideration when establishing appropriate fish transportation methodology.

Water quality parameters of particular concern during transport operations are temperature, dissolved oxygen (DO), carbon dioxide (CO₂), free hydrogen ion activity (pH), and total ammonia nitrogen (TAN) levels. Fish require DO for survival, as it is the primary component for all aerobic activity and cellular metabolism (Moyle and Cech, 2004; Portz *et al.*, 2006). However, oxygen consumption in closed systems during transport effectively removes necessary oxygen, and if oxygen production systems do not meet or exceed consumption demands, hypoxic (low oxygen level) and anoxic (no oxygen) conditions will develop. Low oxygen levels can result in respiratory stress, which can affect swimming performance, equilibrium, and survival (Moyle and Cech, 2004; Herbert and Steffensen, 2005; Portz *et al.*, 2006). As a byproduct of metabolic processes, fish produce CO₂ (≈ 1.4 mg CO₂ per 1.0 mg O₂ consumed under aerobic conditions), which can threaten fish health in transport containers as elevated levels are toxic to fish and can result in hypercapnia and respiratory distress (Colt and Tchobanoglous, 1981; Wedemeyer, 1996; Cech and Crocker, 2002). Elevated CO₂ also functions in lowering water pH and creating acidic conditions, which affects ion transport at gills and leads to blood acidosis (Wood and McDonald, 1982; Wedemeyer, 1996). Also of concern during fish transport are the effects of elevated ammonia. Ammonia can reach toxic levels in closed transport systems, as fish continuously produce TAN as a primary byproduct of protein metabolism (e.g., processing of food) and water consumption. Of particular concern during transportation is the portion of un-ionized ammonia (NH₃⁺), which increases with increasing temperature, salinity, and pH. Un-ionized ammonia is extremely toxic to fish, and can result in loss of equilibrium and eventual fish mortality (Russo and Thurston, 1991). However, what determines the level of toxicity of parameters such as CO₂, TAN, and pH is their concentration in transport media. Therefore, obtaining an accurate estimate of water volume during transport is a critical factor when developing appropriate densities of fish for transport (for a complete review on the effects of water quality on fish during holding see Colt and Tomasso, 2001 and Portz *et al.*, 2006).

Operations at the U.S. Bureau of Reclamation's (Reclamation) Tracy Fish Collection Facility (TFCF; Byron, California) facilitate the removal of fish from water leading to the Bill Jones Pumping Plant, and via fish-hauling practices, provide them with relocation away from the influence of the pumping plant, effectively limiting their likelihood of entrainment and pump associated mortality (Figure 1). Such operations result in

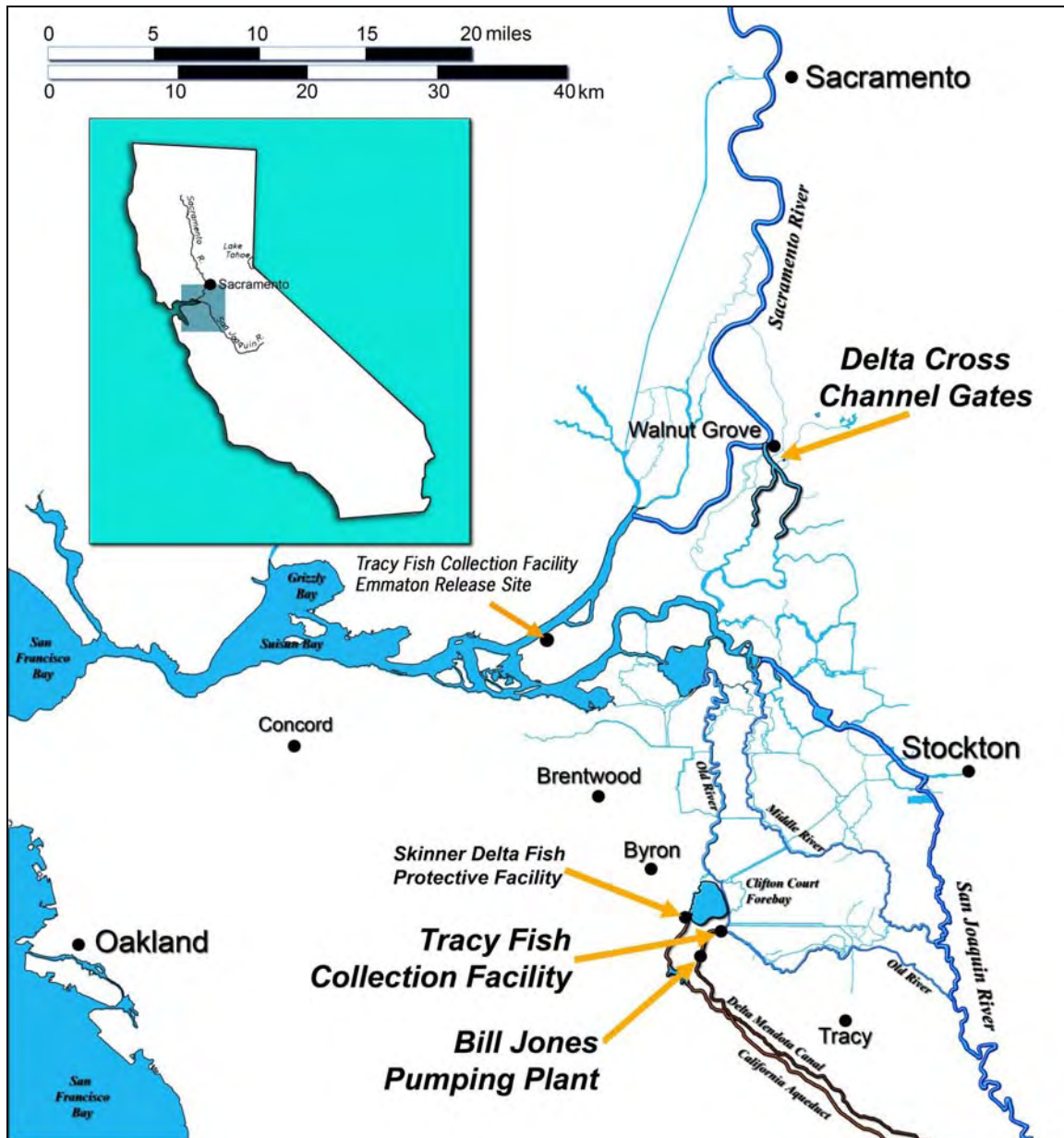


FIGURE 1.—Map of the Sacramento-San Joaquin Delta depicting the Tracy Fish Collection Facility, Bill Jones Pumping Plant, and Emmaton Fish Release Site.

transportation of millions of fish annually, including over 50 species of fish, with threatened delta smelt (*Hypomesus transpacificus*) and endangered winter-run Chinook salmon (*Oncorhynchus tshawytscha*) contributing to the composition of species effected (Brown *et al.*, 1996; <http://www.delta.dfg.ca.gov/Data/Salvage/>).

During routine TFCF operations, fish are salvaged into flow-through holding tanks (Figure 2) that are 6.1 meters (m; 20 feet [ft]) in diameter and 4.7 m (15.4 ft) deep (volume ranges from $\approx 17,000$ to $70,000$ liters [L; $\approx 4,492$ to $18,497$ gallons (gal)] and is dependent on tidal fluctuations) that provide continuous flows of water (at velocities between 0.03 and 0.3 cubic meters per second [m^3/s]; 1.06 and 10.6 cubic feet

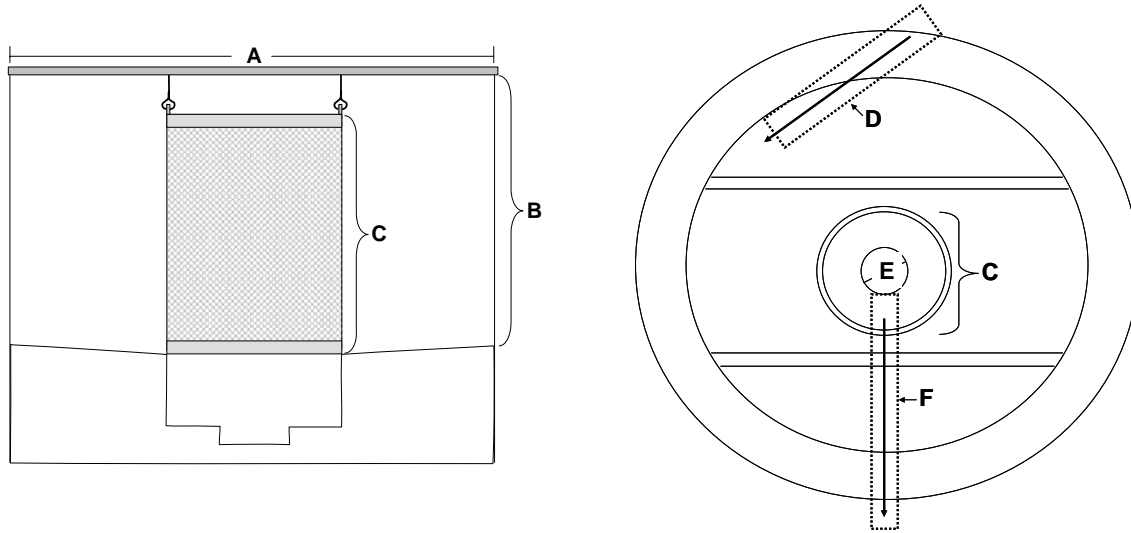


FIGURE 2.— Side view (left) and top view (right) of the Tracy Fish Collection Facility holding tanks used to support fish after collection and prior to hauling. Each of four tanks is (A) 6.1 meters (20 feet) in diameter and (B) 4.7 meters (15.4 feet) deep with conical shaped bottoms. A cylindrical wire mesh screen (C) 2.4 meters (7.9 feet) in diameter rests in the center of the holding tanks. Water enters each of four tanks through a (D) 51-centimeter (20-inch) influent line, passes through the cylindrical screen, (E) 46-centimeter (18-inch) drain opening, and exits through the (F) 51-centimeter (20-inch) holding tank drain.

per second [ft^3/s]) and are maintained for up to 8 hours (hr) until they can be loaded into a TFCF fish-hauling truck (Figure 3) and transported from the southern Sacramento-San Joaquin Delta (SSJD) for release at one of two Reclamation release sites in the central SSJD (Figure 1). Two important stages during this process are fish loading and fish transport. Fish loading consists of draining the holding tank over an approximate 10-minute (min) period, thus restricting contents (e.g., fish, debris, garbage) to 1,400 L (370 gal) of water. Holding tank contents are then drained into a fish haul-out bucket (Figure 4) of equal volume and transferred to a fish-hauling truck. Given the increased density of fish during transfer from holding tank to truck, likelihood of brief exposure (≈ 10 min) to hypoxic conditions increases, making loading a possible water quality limited stage likely to affect health of transported fish. Fish transport consists of hauling fish in a closed (e.g., no additional water provided throughout transport) cylindrical tank (1.2 m [3.9 ft] deep, 4.4 m [14.4 ft] long) that provides continuous pure DO via oxygen diffusing air stones over a maximum distance of 49.9 kilometers (km; 31 miles [mi]). Because of the closed nature of the hauling system, depletion of available DO and accumulation of ammonia and CO_2 are a concern and could potentially lead to harmful conditions for fish.

The objectives of this study were threefold: (1) measure changes in the following water quality during transport: temperature ($^{\circ}\text{C}$), DO, CO_2 , pH, TAN, and total gas saturation (TGS), and measure how these changes were affected by estimated fish densities in the hauling truck; (2) measure the time it takes from fish loading to fish release, and (3) measure water loss (changes in volume) during transport.



FIGURE 3.—The Tracy Fish Collection Facility fish-hauling truck. The tank is cylindrical in shape, 1.2 meters (4 feet) deep, 4.4 meters (14.4 feet) long.



FIGURE 4.—The Tracy Fish Collection Facility fish haul-out bucket.

METHODS

Hauling Truck Water Quality

Water quality was measured during loading, transport, and release stages of the TFCF fish transportation process. Sampling was conducted weekly between June and September 2005, with one additional sample collected in November 2005, and two additional samples collected in June 2006. The sampling period was selected as it coincides with the period of warmest water temperatures in the southern SSJD and, as a function of the thermal affects on fish metabolism (in general, metabolism increases with temperature), likely resulted in highest oxygen consumption, as well as CO₂ and TAN production rates.

Water quality was measured at four stages during the loading, transport, and release process: (1) in the holding tank prior to loading (°C only), (2) after loading, but prior to transport in the hauling truck, (3) after transport, but prior to release, in the hauling truck, and (4) at the most commonly used release site (Emmaton Release Site, Emmaton, California; Figure 1). An 18.9-L (5-gal) bucket was used to sample water from the surface of the holding tank prior to transport. Water quality measurements in the fish-hauling truck were taken at ≈ 50 % water depth. Samples were collected at the release site 38 m (125 ft) offshore and at the water's surface, except for temperature, which was also recorded at the following depths off bottom: 1.5, 4.6, 7.6 m (4.9, 15.1, 24.9 ft).

Temperature and DO were measured at each stage using a pre-calibrated YSI meter (Yellow Springs Inc., Yellow Springs, Ohio); CO₂ was measured using a drop count titration kit (CHEMetrics, Inc., Calverton, Virginia); pH was measured using an Oakton pH meter (Vernon Hills, Illinois); TGS was measured using a satumeter (Sweeney Aquametrics, New Haven, Connecticut); TAN was measured using a water quality test kit (LaMotte Company, Chestertown, Maryland); and NH₃⁺ was calculated using tables provided by Wedemeyer (1996), and incorporating TAN, pH, and temperature data collected during our study.

Truck Water Loss

Manufacturer details provided TFCF fish-hauling truck tank dimensions and maximum water capacity (8,000 L; 2,114 gal). However, filling the truck to maximum capacity is not a common practice at the TFCF and the truck tank is not completely sealed during hauling, resulting in water loss during transport. To obtain an accurate estimate of water volume (and subsequent water volume loss during transport) as a function of depth, 1 L (0.26 gal) of yellow-green dye (Bright Dyes, Miamisburg, Ohio; maximum absorbance = 490/520 nanometers) was injected into known water levels within the TFCF haul truck, and water samples were taken at each of the following depths below tank surface: 51, 38, 25 and 13 centimeters (cm; 1.7, 1.2, 0.8, and 0.4 ft). Water samples were analyzed using a spectrophotometer, absorbance was measured, and water volumes were calculated at

each depth. Similar methods were employed to determine the volume of water for both TFCF fish-count and fish-loading buckets.

Oxygen Production Rates

The TFCF fish-hauling system employs the use of microbubble oxygen diffuser air stones (70 × 8 cm [2.3 × 0.3 ft], MBD 600, Point Four Systems Inc., Coquitlam, British Columbia), which, when operated at full capacity are capable of providing 18 L/min (4.8 gal/min) of pure oxygen to the water. To test this assumption and the TFCF fish-hauling tank oxygenation system, oxygen cylinders were set to 40 pounds per square inch (psi; 2.8 bar), and flow meters controlling O₂ flow to tank air stones were set to 18 L/min (4.8 gal/min). Water level in the truck was adjusted to 25.4 cm (10 inches [in]) below the tanks surface (6,804.6 L [1,797.6 gal]). A blower was attached to the TFCF haul-truck ventilation system, and the truck water was mixed in order to mimic possible cooling effects associated to wind passage and sloshing during driving. DO (mg/L) and temperature (°C) were recorded using a YSI 85 meter every 15 min over a 75-min period.

Fish Densities

Densities of fish during each transport were estimated from series of 10-min entrainment sub-samples taken at 2-hr intervals prior to each transport. During 10-min entrainment sub-sampling, all fish entering the holding tank were salvaged, counted, identified to species, and the first 24 individuals of each species were measured for fork length. These data were then extrapolated (multiplied by 12) to estimate the number of fish passing into a holding tank over each 2-hr period. Fish weights, necessary to establish densities during transport, were determined by establishing length-weight regression relationships for individual species of fish sampled from holding tanks.

RESULTS AND DISCUSSION

Mean transport duration and distance over the length of our study were 59.4 min and 49.9 km (31 miles), respectively (n = 19; distance and duration reported as function of a one-way trip). However, mean time from the point at which the holding tank was completely drained to the release of all fish at the release site was 79.8 minutes. During typical fish loading, spectrophotometer estimates indicate fish are transferred from holding tank to truck in a haul-out bucket containing a mean water volume of 1402 L (370.5 gal). It should be taken into consideration that our measurements were conducted using a haul-out bucket void of fish and debris, and the addition of fish and debris will displace water. This relationship is important, because increased densities of fish (and debris) in the fish haul-out bucket can displace a significant volume of water, which is lost through haul-out bucket screens, ultimately reducing the volume of water available for fish. Therefore, increased confinement of fish in the haul-out bucket and smaller water volume from which available oxygen can be removed, results in elevated rates of oxygen consumption leading to rapidly deteriorating water quality. TFCF fish-hauling

truck tanks, filled to capacity, hold 8,097 L (2139 gal) of water, although the mean volume at the onset of transport was 6,691 L (1768 gal; equivalent to 24.6 cm [9.7 in] below the top of the tank; Figure 5). Water loss throughout transport (mean = 147 L (38.8 gal)) was not as significant as initially suspected and resulted in a mean post-transport volume of 6,544 L (1,792.3 gal).

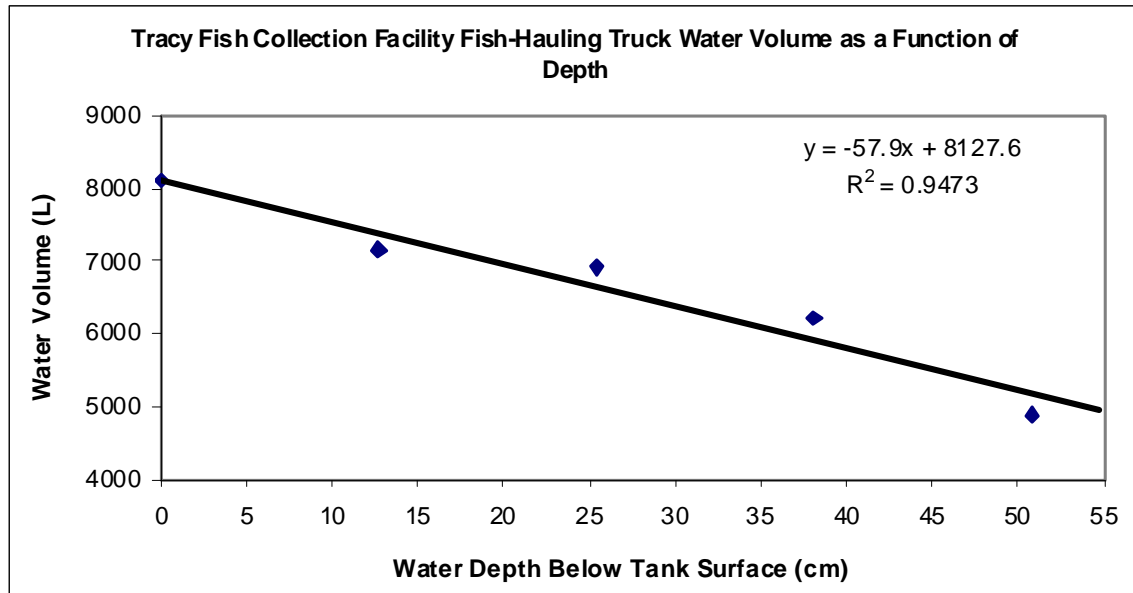


FIGURE 5.—Tracy Fish Collection Facility fish-hauling truck tank water volume as a function of water depth below tank surface; measured as depth from top of tank to water surface.

Total number of fish, and haul-out bucket and truck tank densities ranged from 372 to 503,319 fish, and from 1.3–86.6 and 0.3–65.4 g of fish weight/L (0.2–11.7 and 0.04–8.8 oz of fish weight/gal), respectively (Table 1). However, the mean number of fish and density in the transport truck were 45,279 fish and 8.6 g/L (1.2 oz/gal), respectively. Only two samples contained >100,000 fish, indicating the majority of our post-transport water quality conditions are a function of low fish densities during transport. The majority of species transported during the study were Sacramento splittail (*Pogonichthys macrolepidotus*; ST; 68%) and fish labeled as “others” (21%), but the high numbers of both species can primarily be attributed to two large truckloads of common carp (*Cyprinus carpio*; 170,000 individuals) and ST (552,000 individuals) on June 7 and 14, 2006 (Table 2). Removing these two samples from the analysis, threadfin shad (TFS; 64%) contributed to the majority of species transported (n = 17).

TABLE 1.—Percentage of species transported, mean number, and density of fish transported.

| Species | Percent of Total |
|---|------------------------|
| Sacramento splittail (<i>Pogonichthys macrolepidotus</i>) | 69% |
| Others—primarily common carp (<i>Cyprinus carpio</i>) | 21% |
| Threadfin shad (<i>Dorosoma petenense</i>) | 7% |
| White catfish (<i>Ameiurus catus</i>) | 1% |
| Striped bass (<i>Morone saxatilis</i>) | 1% |
| American shad (<i>Alos sapidissima</i>) | < 1% |
| Channel catfish (<i>Ictalurus punctatus</i>) | < 1% |
| Combined centrarchids | < 1% |
| Chinook salmon (<i>Onchorhynchus tshawytscha</i>) | < 1% |
| Steelhead (<i>Onchorhynchus mykiss</i>) | < 1% |
| Yellowfin goby (<i>Acanthogobius flavimanus</i>) | < 1% |
| Delta smelt (<i>Hypomesus transpacificus</i>) | 0% |
| Mean number of individuals transported | 45,279 |
| Mean fish transportation density | 8.6 g of fish/L |

TABLE 2.—Maximum and minimum water quality levels observed in the Tracy Fish Collection Facility fish-hauling truck and at the Emmaton Release Site. Water quality levels were monitored between June 2005 and June 2006.

| Water Quality Parameter | Pre-Haul | | Post-Haul | | Release Site | |
|-------------------------|----------|---------|---------------------|---------|--------------|---------|
| | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum |
| Temperature (°C) | 25.3 | 15.2 | 25.1 | 15.8 | 23.0 | 15.2 |
| Dissolved oxygen (mg/L) | 12.9 | 6.7 | > 19.0 ¹ | 5.8 | 10.9 | 7.4 |
| Carbon dioxide (ppm) | 0.0 | 0.0 | 20.0 | 0.0 | n/a | n/a |
| pH (standard units) | 7.8 | 7.0 | 7.9 | 6.5 | 8.7 | 7.5 |
| Total ammonia (ppm) | 0.6 | 0.2 | 2.0 | 0.4 | n/a | n/a |

¹The highest dissolved oxygen (mg/L) concentration that will be displayed by the YSI 85 is 19.0 mg/L.

Range of water temperatures (15.2–25.3 °C), DO (5.8–19.0 mg/L), pH (6.48–8.66), and NH_3^+ (0.002–0.01 mg/L) throughout all stages of sampling remained within acceptable limits for long-term fish culture as recommended by Wedemeyer (1996), and are therefore deemed adequate for short-term transport of fish (Table 2). Once loaded into the fish-hauling truck, maximum increases (+0.9 °C) and decreases (-0.8 °C) in water temperature during transport were not significant enough to pose serious health or performance risks to fish (Table 3). However, maximum differences in temperature from holding tank to post-transport in the hauling truck tank (-1.9 °C and +1.3 °C), and from holding tank to the fish release site (-4.6 °C and +1.3 °C) in particular, are above recommended rates of thermal acclimation and may result in mild thermal stress and affect the ability of fish to escape predation upon release (Coutant, 1973; Webb and Zhang, 1994; Summerfelt *et al.*, 2001; Ward and Bonar, 2003).

The highest density of fish 65.4 g/L or 9.2 g/m³ (8.8 oz/gal or 0.01 oz/ft³) observed during sampling is above recommended guidelines 50 g/L (6.8 oz/gal) for short-term transport (< 3 hr; Carmichael *et al.*, 2001). Regardless, DO levels increased throughout transport (from 9.0 to 15.3 mg/L) at the highest density, indicating the TFCF fish-hauling truck oxygenation system is capable of providing DO at a rate (1281.5 mg/min at 24.1 °C) that will support high densities of fish. TAN levels during transport densities of 65.4 g/L reached 2 mg/L and, if paired with elevated pH (basic) and water temperature, could result in toxic levels of NH_3^+ . However, CO_2 production, resulting in levels of 20 mg/L counteracted the toxic effects of ammonia. Elevated CO_2 resulted in a drop in pH (6.48), which in turn reduced the proportion of the toxic form of ammonia to safe levels ($\text{NH}_3^+ = 0.002$ mg/L). Though elevated CO_2 levels effectively reduced the proportion of toxic NH_3^+ in the transport media, levels > 10 mg/L are not recommended for fish culture and may have an adverse affect on fish during short-term transport. Wedemeyer (1996) reports CO_2 levels > 20 mg/L can be detrimental to salmonids and other sensitive cold-water species. However, mortality, as a function of blood acidosis, is typically not common until CO_2 levels > 100 mg/L are observed (Wedemeyer, 1996). Moderately high CO_2 levels (20–40 mg/L) result in mild hypercapnia, reducing the oxygen carrying capacity of blood hemoglobin, and the ability of blood to transport oxygen to tissues (Wedemeyer, 1996). However, during high fish densities and elevated CO_2 levels during transport, the TFCF fish-transport truck oxygenation system maintained oxygen levels above saturation, effectively limiting the negative effects of mild hypercapnia.

TABLE 3.—Changes in water temperature (ΔT) experienced by fish during the Tracy Fish Collection Facility loading, hauling, and release procedures. Abbreviations are as follows: H.Tank = holding tank, H.Bucket = haul-out bucket, Pre-Haul = truck water sample prior to hauling fish, Post-Haul = truck water sample after hauling fish, and Release Site = water sample from fish release site.

| | H. Tank to H. Bucket | H. Tank to Pre-Haul | H. Tank to Post-Haul | H. Tank to Release Site | H. Bucket to Pre-Haul |
|---------|------------------------|---------------------------|-----------------------|--------------------------|---------------------------|
| Mean | 0.0 | -0.6 | -0.6 | -2.1 | -0.1 |
| Median | -0.6 | -0.3 | -0.9 | -2.4 | 0.1 |
| Max (-) | -1.1 | -2.1 | -1.9 | -4.6 | -1.4 |
| Max (+) | 0.3 | 0.4 | 1.3 | 1.2 | 0.5 |
| | H. Bucket to Post-Haul | H. Bucket to Release Site | Pre-Haul to Post-Haul | Pre-Haul to Release Site | Post-Haul To Release Site |
| Mean | -0.1 | -1.7 | 0.0 | -1.5 | -1.5 |
| Median | -0.2 | -1.9 | 0.0 | -1.7 | -1.5 |
| Max (-) | -0.9 | -3.5 | -0.8 | -3.4 | -2.8 |
| Max (+) | 1.0 | 1.5 | 0.9 | 1.2 | 0.6 |

Though the highly productive and efficient truck oxygenation system functions in supplying adequate DO levels to support high densities of fish, the system is adjusted to operate at maximum capacity and not regulated as a function of fish density. Operating the truck oxygenation system at full capacity resulted in a maximum TGS level of 106.1% during testing. This value is likely lower than typically observed during transport because TGS was only measured on two occasions, and on both (June 7 and 14, 2006), densities of fish were high. During the transport of low densities of fish (< 8 g/L) DO levels were commonly > 18 mg/L and, it is plausible during such conditions TGS could reach levels above those recommended for fish culture (> 110 %; Wedemeyer, 1996). Elevated TGS levels can lead to gas bubble disease, the formation of gas bubbles in the heart and other areas of the circulatory system, which ultimately leads to fish mortality.

RECOMMENDATIONS

Wedemeyer (1996) indicates that TGS levels > 110% will eventually lead to gas bubble disease. It is therefore important that additional TGS samples be recorded at low fish densities and high DO production rates to estimate maximum levels of TGS during transport. This is particularly important at the TFCF because threatened and endangered species, such as delta smelt, Chinook salmon, and steelhead trout are commonly salvaged during seasons when more common species are in low abundance, and are therefore transported at lower densities (Reyes personal communication, 2008).

We also recommend the initiation of water quality monitoring in the fish haul-out bucket. We estimated very high fish densities (up to 86.6 g fish/L [11.7 oz/gal]) in the haul-out bucket, and though exposure time is minimal (≈ 10 min), there is a possibility of hypoxic exposure and rapid deterioration of other important water quality parameters over a short-time interval.

Two fish-hauling truck water quality samples were obtained at transport densities of >17 g fish weight/L (> 0.002 oz/gal). High densities of fish during transport lead to deteriorating water qualities, which pose a threat to fish health. We recommend additional samples be acquired during periods of warm temperatures and high fish salvage to increase sample size and improve the reliability of our estimates.

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