CONTRIBUTED PAPERS

Results of a Two Year Fish Entrainment Study at Morrow Island Distribution System in Suisun Marsh

Cassandra Enos (DWR) cenos@water.ca.gov, Jessica Sutherland (DWR), Matthew L. Nobriga (CALFED)

Introduction

Suisun Marsh is the largest contiguous brackish marsh on the West Coast of the United States, representing approximately 12% of California's remaining wetland habitat. Although the marsh is a significant nursery area for many fish species (Meng et al. 1994; Meng and Matern 2001; Matern et al. 2002), long-term monitoring has shown declines in many Suisun Marsh native fishes (Matern et al. 2002; Matern and Moyle 1994; Meng and Matern 2001; Schroeter and Moyle 2004). Some native species have declined to the point that they are considered threatened or endangered, including: Chinook salmon *Oncorhynchus tshawytscha* (winter and spring-runs) and delta smelt *Hypomesus transpacificus*. Other recreationally important fish, like striped bass *Morone saxatilis*, have also declined. Factors thought to contribute to these declines include alteration of the estuarine hydrology, introduction of alien species, pollution, and water diversions (Meng and Matern 2001; Matern et al. 2002).

Water diversions are generally assumed to kill great numbers of fish, including migratory fish such as salmon and steelhead (Moyle and Israel 2005). Herren and Kawasaki (2001) counted 366 water control structures distributed throughout Suisun Marsh, including water diversions and drains (S. Chappell, pers. comm.). These water control structures typically consist of one culvert ranging in size from 0.9 (36 in) to 1.2 m (48 in). Although over half of the managed wetland acreage in the marsh is flooded through unscreened diversions (DFG 2007), few data are available regarding fish entrainment dynamics in Suisun Marsh. Picard et al. (1982) studied abundance and size of fish entrained at the Roaring River Distribution System intake. However, this structure, which consists of eight 1.5 m (60 in) culverts, is much larger than the typical Suisun Marsh diversions. The California Department of Fish and Game (DFG) sampled eight diversions in Suisun Marsh periodically from April 1996 until May 1998. Although no analysis of the DFG data was conducted, the raw catch totals indicate that most diversions in the Marsh are likely not diverting large numbers of fish and are likely having a negligible impact on fish populations (Moyle and Israel 2005). Moyle and Israel (2005) noted studies in the Central Valley and Sacramento-San Joaquin Delta have found that the principal species entrained in small diversions (<1.1 m^3/s (39 ft^3/s)) are alien or abundant natives, and questioned whether screening small diversions would improve fish populations, particularly populations of listed species. They addressed the need to consider alternatives to fish screens, such as adjusting the timing and volume of water diversions, to reduce entrainment. Detailed understanding of the factors influencing short-term entrainment may be used to develop diversion strategies that reduce entrainment at unscreened diversions in Suisun Marsh.

From September 2004 to June 2006, we studied fish entrainment at the Morrow Island Distribution System (MIDS) in Suisun Marsh (Figure 1). The purpose of the study was to evaluate entrainment losses of fishes (with a focus on delta smelt and salmonids) at the intakes over several months under various operational configurations to provide data on the site-specific impact of the MIDS diversion. Our goals were to inform decisions about fish screening needs, improve future entrainment/particle tracking modeling studies, and find operational configurations that minimize fish entrainment. We also sampled fishes in Goodyear Slough (GYS) near the diversion to compare the composition of entrained fishes to samples of fish potentially vulnerable to entrainment.

Study Area

The MIDS is located off of GYS in western Suisun Marsh, approximately 9 km (5.6 mi) northeast of the Solano-Contra Costa County lines at the Benicia-Martinez Bridge (Figure 1). GYS is a 20-30 m (66-98 ft) wide, 2-3 m (6.5-10 ft) deep channel fringed with bulrushes *Scirpus* spp., cattails *Typha* spp., and common reed *Phragmites* *australis* (Culberson et al. 2004). The MIDS intake consists of three 1.2 m culverts located on the eastern bank of GYS, approximately 1.6 km (1 mi) south from the mouth of the Slough. MIDS is a gravity-flow system; the system fills and drains due to differential water levels caused by tidal action in GYS, Grizzly Bay, and within the system itself, in combination with variable gate configurations. No pumps or other mechanical devices are used to move water through the system. The system fills from GYS only during periods when the water level in GYS is higher than in the system. As the water level in the system reaches equilibrium with the level in GYS, flow through the culverts decreases.

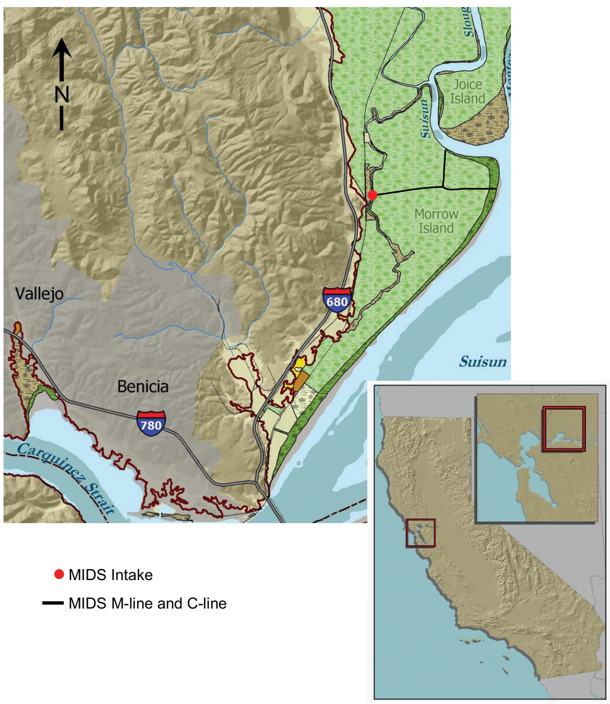

Figure 1 Morrow Island distribution site map

MIDS operates primarily to drain water from adjacent managed wetlands to Grizzly Bay in order to increase circulation and reduce salinity in Goodyear Slough. The system is also used to provide water to managed wetlands, as needed, for initial filling, circulation, and drainage cycles. In general, when the MIDS intake is open and operating, approximately 1/3 of the volume of water passing the intake facility on a flood tide within Goodyear Slough is diverted into the MIDS for use by individual land ownerships. During periods when landowners are not actively diverting water to their ponds ("turnouts to ponds closed") approximately 1/6 of the Goodyear Slough flow is diverted into and through MIDS. In this configuration MIDS can be operated as a tidally-influenced flow-through channel system between Goodyear Slough and Suisun Slough/Grizzly Bay.

The contractual requirement for the Bureau of Reclamation and Department of Water Resources (DWR) is to provide water to the ownerships so that lands may be managed according to approved local management plans. To meet these needs, the typical MIDS annual operation includes the following actions: preseason fill, circulation drain/fill, end-of-season drain, end-of-season leaching, brood pond circulation, and maintenance drain (Table 1). Challenges to meeting these operation requirements include: regulatory restrictions and closures, sediment accretion, local tides/meteorological conditions, and individual landowner requests.

Methods

Samples were collected periodically from 23 September 2004 through 26 May 2005 and 29 September 2005 through 2 June 2006 (Table 2). These sampling periods covered two operating seasons for MIDS and the period when delta smelt and salmonids would most likely be present in western Suisun Marsh. Samples were collected during both day and night based on the schedule of the high tides. The sampling frequency was revised after the first year to better reflect seasonal fish occurrence. Intake samples were collected from two culverts (approximately 2 m (6.6 feet) apart); samples were also collected in GYS. The sampling methods are detailed below.

During the 2005-06 sampling season, we conducted five 24-hour sample sessions. During each 24-hour session, sampling was conducted during both high tides within the 24-hour period. Samples were collected only during high tides, when MIDS was filling, which was approximately 10-12 hours of the 24-hour period. These samples allowed for evaluation of diel differences in fish entrainment, which is often substantial (Nobriga et al. 2004). The 24-hour sessions began 6 April 2006 following an increase in fish numbers observed in the intake samples.

Table 1 Summary of MIDS management actions and intake gate settings

Management Action	*Timing*	*Purpose*	*Intake exterior gate setting*
Pre-season fill	Sept 15 - Oct 1	Fills MIDS and provides GYS water for landowners to fill ponds	46-91 cm (18-36 in)
Circulation drain/fill	Mid-late Oct - mid-late Jan	Provides GYS water for circulation in ponds	0-1.2 m (0-48 in)
End-of-season drain	February	Allows landowners to deeply drain ponds	closed
End-of-season leaching	February - May	Provides GYS water for quick flood then drain to remove salts in ponds	46-91 cm followed by closed
Brood pond circulation	March 1 - July 15	Provides GYS water for circulation for brood pond management	46 cm - 1.2 m
Maintenance drain	Late spring - Sept 15	Allows landowners to drain ponds for summer maintenance	closed

Table 2 Sampling schedule for 2004-05 and 2005-06 sampling seasons and typical MIDS operation schedule

<table>
<tr><th></th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th></tr>
<tr><td colspan="13">2004-2005 Sampling Season Schedule</td></tr>
<tr><td>GYS sampling</td><td></td><td colspan="2">1d/m</td><td>1d/2wk</td><td colspan="3">1d/wk</td><td>2d/wk</td><td>1d/wk</td><td></td><td></td><td></td></tr>
<tr><td>Intake sampling</td><td></td><td colspan="2">3d/m</td><td>3d/ 2wk1</td><td colspan="5">3d/wk</td><td></td><td></td><td></td></tr>
<tr><td>UC Davis sampling</td><td colspan="12">1d/m</td></tr>
<tr><td colspan="13">2005-2006 Sampling Season Schedule</td></tr>
<tr><td>GYS sampling</td><td></td><td colspan="2">1d/m</td><td>1d/2wk</td><td colspan="3">1d/wk</td><td>2d/wk</td><td>1d/wk</td><td></td><td></td><td></td></tr>
<tr><td>Intake sampling</td><td></td><td>6d/m1</td><td>1d/m</td><td>1d/2wk</td><td colspan="2">1d/wk</td><td colspan="3">3d/wk</td><td></td><td></td><td></td></tr>
<tr><td>UC Davis sampling</td><td colspan="12">1d/m</td></tr>
<tr><td colspan="13">MIDS Operation</td></tr>
<tr><td></td><td>Initial flood-up</td><td colspan="4">circulation</td><td colspan="4">leach/drain</td><td colspan="3">maintenance drain</td></tr>
</table>

1.Sampling was conducted 2 days per week during initial flood-up for a maximum of three weeks.
d/m - days per month
d/wk - days per week

MIDS Intake Sampling

Fish were collected using two 1.6 mm (0.06 in) -mesh hooped plankton nets. This mesh size is equivalent to that used by DFG in their 20-mm survey (Dege and Brown 2004); it effectively retains fish larger than about 15 mm (0.6 in). We sampled only the two outer culverts because the intake structure was not wide enough to accommodate three nets. Samples from the two culverts provided sufficient data to allow for estimation of total entrainment through the intake structure. The nets were attached to the culverts via coupling rings following a design employed by Matica and Nobriga (2005). When the rings were engaged, they sampled 100% of the flow diverted through the two culverts. Net contents were collected approximately every two hours. At the end of each two-hour sampling interval, the nets were retrieved and samples were placed into separate, labeled containers. Up to 20 haphazardly selected individuals of each species from each sample were measured to TL or FL if the caudal fin was forked. When more than 20 individuals of a species were present in a sample, the remaining individuals were tallied, but not measured. When possible, fish were identified to species on site. Fish that could not be identified on site were preserved in 10% formalin and identified in the laboratory. All samples not preserved for laboratory analysis were returned to the water. Fish smaller than 20 mm (0.8 in) were collected weekly (21 April 2005 through 23 May 2005 and 6 April 2006 through 2 June 2006) and sent to the laboratory for identification. These samples are still being processed. This report presents results primarily for fish > 20 mm. This has no effect on results for salmonids which do not use Suisun Marsh when they are < 20 mm. It may have a small effect on delta smelt results, but any bias is likely extremely minor (see Discussion).

Goodyear Slough Sampling

We used a 30.5 m (100 ft) by 3.05 m (10 ft) purse seine with a stretched mesh size of 4.8 mm (0.2 in) to sample fishes in GYS. Samples were collected coincidentally with the intake samples, but the purse seine was mainly effective at catching fishes >35 mm (1.4 in). This mesh size is sufficient to retain emigrating salmonids, which are usually >35 mm when they reach the estuary. All samples were collected within 100 m (328 ft) north or south of the intake structure. Approximately 8-12 seine hauls were conducted during each sampling period. All fish collected in GYS were identified, measured, and counted following the same procedures as the intake samples.

All fish collected in GYS were identified, measured, and counted following the same procedures as the intake samples.

Water Quality Sampling

Water quality data, including water temperature (°C) and electrical conductivity (mS/cm) were taken from the DWR water quality monitoring station S-35, which is approximately 140 m (460 ft) upstream from the intake structure. Water transparency (Secchi disk; cm) was collected for each sample period. During the 2005-06 sampling season dissolved oxygen (mg/L) and temperature were also measured in MIDS during each sampling period.

Water level (stage) data were collected outside the intake in GYS and behind the intake in Morrow ditch every 15 minutes. The water level data, in conjunction with gate operation data, were used to estimate flow through the intake structure. DWR staff developed a computer program to estimate flow through the north and south culverts during each sampling period. We used the program to estimate velocities (m/s), flow rates (m^3/s), and total sampling period volumes (m^3).

Results

The combined two-year total sample times for the north and south culverts were 589 and 594 hours, respectively (Table 3). The volume of water diverted per sampling period ranged from about 700 m^3 (24,720 ft^3) to 29,400 m^3 (1,038,000 ft^3) per culvert based on gate opening and differences in water levels of this gravity flow system. We estimated the percentage of water diverted from GYS during each sampling period using modeled data for GYS and the MIDS intake. The percentage of entrained GYS volume sampled averaged 11% (0.65% to 43%) in 2005 and 16% (1.5% to 39%) in 2006 (Figures 2 and 3). We sampled GYS on 56 days, conducting a total of 508 purse seine hauls during the sampling period (Table 3).

Water temperatures ranged from 7.0 °C (44.6 °F) to 22.1 °C (71.8 °F) in 2004-05 and 8.4 °C (47.1 °F) to 24.4 °C (75.9 °F) in 2005-06. Mean daily electrical conductivity ranged from 1.48 mS/cm to 18.65 mS/cm in 2004-05 and 1.16 mS/cm to 17.10 mS/cm in 2005-06 (Figure 4). Transparency ranged from 10-26 cm (4-10 in) in 2004-05 and 9-37 cm (3-15 in) in 2005-06. In 2005-06 dissolved oxygen ranged from 2.18 -11.03 mg/L.

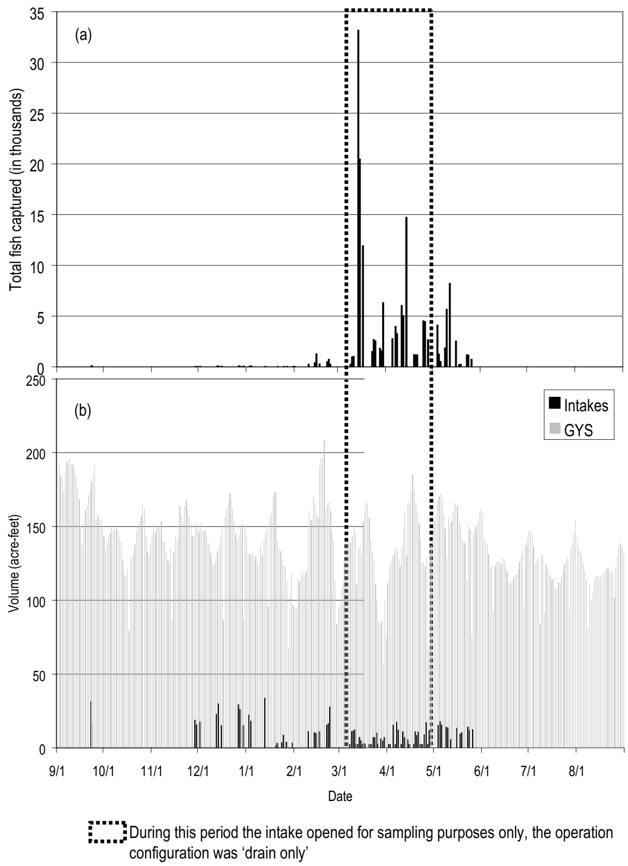

Figure 2 2004-05 sampling season results for (a) total fish entrained in MIDS culverts, and (b) modeled volume in GYS per flood tide and volume sampled in MIDS

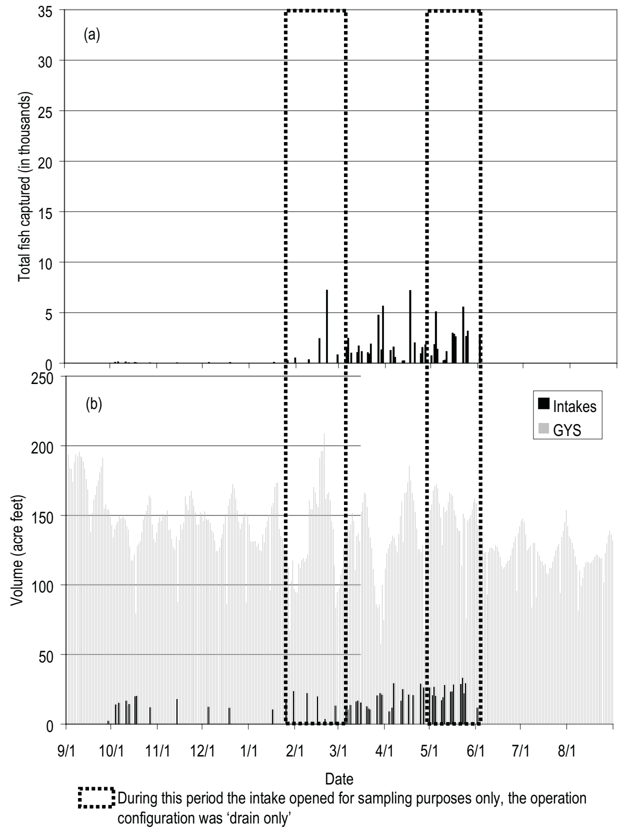

Figure 3 2005-06 sampling season results for (a) total fish entrained in MIDS culverts, and (b) modeled volume in GYS per flood tide and volume sampled in MIDS

We collected 20 fish species in 2005 and 22 species in 2006 from water diverted through the culverts (Table 4). Threespine stickleback *Gasterosteus aculeatus*, was the most abundant species entrained (95% in 2005; 90% in 2006). Prickly sculpin *Cottus asper*, accounted for most of the remainder (4% in 2005; 8% 2006). Both of these fishes are known to aggregate on or near instream structures. We collected only two fall-run sized Chinook salmon (south culvert, 2006) and no delta smelt from diverted water. Other species of management importance, such as native splittail *Pogonichthys macrolepidotus*, salmonids, osmerids, and nonnative striped bass were also among the least entrained species (<1% of total catch). We only observed six striped bass > 20 mm in culvert samples. Likewise, age-1 and older splittail were captured in extremely low numbers (9 individuals), though somewhat high numbers of young-of-year splittail were captured in the spring (666 individuals).

In GYS purse seine hauls, we collected 17 species in 2005 and 21 species in 2006 (Table 4). As with the culvert samples, threespine stickleback was the most abundant species (74% in 2005; 39% in 2006), while prickly sculpin (11% in 2005; 16% in 2006) and inland silverside *Menidia beryllina*, (4% in 2005; 24% in 2006) comprised most of the remainder. We collected 4 delta smelt from GYS in 2005 and 1 in 2006. We collected no Chinook salmon in 2005 and 3 fall-run size Chinook salmon in 2006. We collected 382 splittail and 86 striped bass in GYS. Most of the splittail (355) and all the striped bass were age-1 or older.

Peak entrainment occurred at night, accounting for 70% and 79% of total entrainment at the north and south intakes, respectively during the 24-hr sampling events (Figure 5)

.

Table 3 Summary of sampling effort for 2004-05 and 2005-06 sampling seasons

	2004-05 Sampling Season			*2005-06 Sampling Season*		
	North Intake	*South Intake*	*GYS*	*North Intake*	*South Intake*	*GYS*
No. of samples	142	145	221	154	155	514
Volume sampled (m3)	506,622	488,582	42,710+8542	655,323	660,303	96,992+11,865
Mean volume (m3+SD)	8,171+5351	7,880+4,965	N/A	11,497+4,867	11,584+4861	N/A
Volume range (m3/s)	696 - 29,391	696 - 29,391	N/A	1,173-29,391	1,504-29,391	N/A
Total sampling time (h)	299	296	N/A	290	298	N/A
Mean sample duration (min +SD)	121+36	121+36	N/A	113+26	115+27	N/A

N/A Not Available

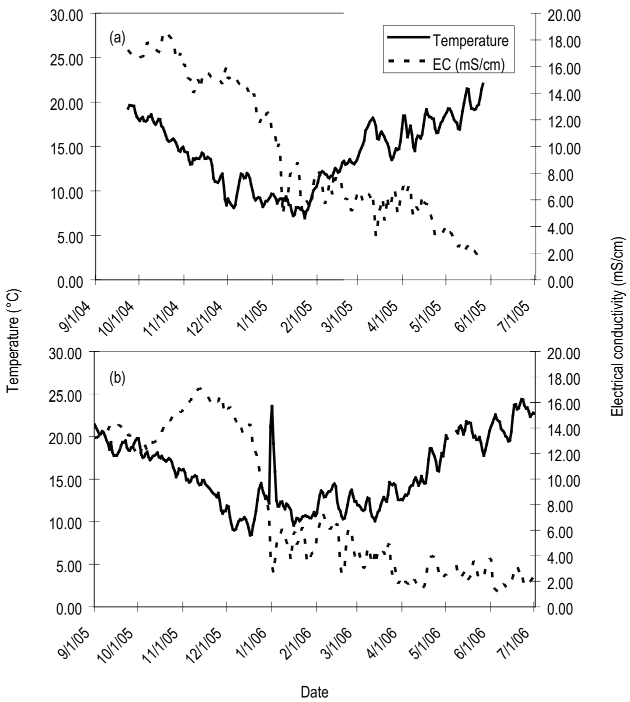

Figure 4 GYS electrical conductivity and temperature data for (a) 2004-05 sampling season, and (b) 2005-06 sampling season

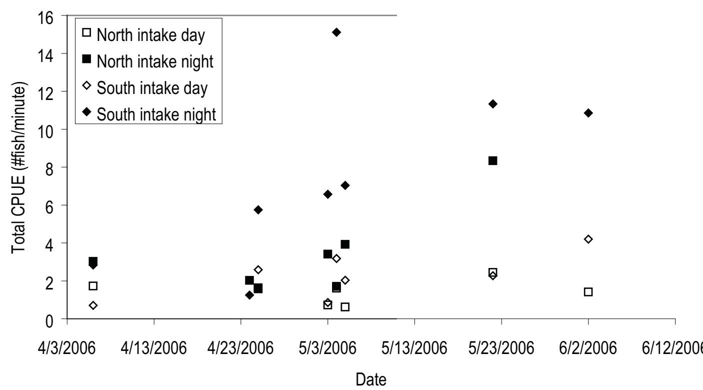

Figure 5 Total catch per unit effort for MIDS 24-hour samples from the 2005-06 sampling season

Table 4 Number of fish collected and their length ranges for the MIDS 2004-05 and 2005-06 sampling seasons

		2004-05 Sampling Season						2005-06 Sampling Season					
		North Intake		South Intake		GYS Seine		North Intake		South Intake		GYS Seine	
Latin name	Common name	Count	FL (mm)	Count	FL (mm)	Count	FL (mm)	Count	FL (mm)	Count	FL (mm)	Count	FL (mm)
Acanthogobius flavimanus	Yellowfin goby	24	15-152	33	12-137	16	50-155	46	17-188	58	20-188	23	40-180
Acipenser transmontanus	White Sturgeon	0		0		0		0		0		1	318
Alosa sapidissima	American shad	1	99	1	76	12	44-217	0		2	63-96	30	66-210
Ameiurus catus	White catfish	1	720	0		0		0		3	52-370	4	51-330
Ameiurus melas	Black bullhead	0		0		0		0		1	203	0	
Ameiurus nebulosus	Brown bullhead	1	254	0		0		0		0		*1*	*110*
Catostomus occidentalis	Sacramento sucker	2	51	0		21	356-514	0		3	40-241	*30*	*32-508*
Clupea pallasi	Pacific Herring	2	37-38	1	27	0		0		0		*0*	
Cottus asper	Prickly sculpin	3,896	15-137	2,645	17-118	345	18-112	3,306	15-149	3,989	12-150	*316*	*22-103*
Cyprinus carpio	Carp	9	38-508	6	30-711	17	267-705	11	24-514	38	25-502	*17*	*170-749*
Dorosoma petenense	Threadfin shad	3	60-102	11	57-112	22	54-101	3	49-88	10	26-84	*24*	*47-91*
Gambusia affinis	Western mosquitofish	0		1	28	1	23	0		1	19	*0*	
Gasterosteus aculeatus	Threespine stickleback	93,144	10-69	65,969	10-67	2414	15-64	35,032	7-69	42,141	12-71	*779*	*13-67*
Hypomesus transpacificus	*Delta smelt*	0		0		4	56-68	0		0		1	64
Hysterocarpus traski	*Tule perch*	5	25-37	9	31-130	9	33-185	46	31-162	50	31-188	12	45-173
Lepomis macrochirus	*Bluegill*	1	25	0		0		2	35-87	11	41-101	1	43
Leptocottus armatus	*Pacific staghorn sculpin*	2	49-80	4	12-104	2	57-65	0		4	29-105	1	63
Lucania parva	*Rainwater killifish*	284	18-43	401	18-44	27	24-43	180	19-46	525	18-50	14	28-45
Menidia beryllina	*Inland silverside*	57	12-92	20	22-87	119	33-101	7	22-90	7	28-72	465	23-106
Morone saxatilis	*Striped bass*	1	120	3	99-154	56	112-762	0		2	100-125	30	104-737
Onchorhyncus tschawytscha	*Chinook salmon*	0		0		0		0		2	39-44	3	45-88
Onchrhyncus mykiss	*Steelhead*	0		0		0		0		0		0	
Platichthys stellatus	*Starry flounder*	0		0		0		0		1	40	0	
Pogonichthys macrolepidotus	*Sacramento splittail*	8	37-254	31	19-298	164	32-438	65	22-112	571	22-230	218	9-368
Pomoxis nigromaculatus	*Black Crappie*	0		0		0		2	86-110	2	95-190	1	120
Ptychcheilus grandis	*Sacramento Pikeminnow*	0		0		0		0		0		0	
Spirinchus thaleichthys	*Longfin smelt*	19	30-81	99	20-115	14	55-102	2	36-73	4	37-72	2	82-83
Tridentiger bifasciatus	*Shimofuri goby*	*14*	*32-109*	*12*	*30-108*	*1*	*102*	*69*	*36-110*	*73*	*36-118*	*2*	*64-80*

Discussion

We sampled over 2.3 million m^3 (81.2 million ft^3) of diverted water during our monitoring of the intake structure. Despite this, entrainment of special-status fishes was exceptionally low (2 Chinook salmon and no delta smelt). Rather, two species that associate with instream structures, threespine stickleback and prickly sculpin, comprised most of the entrained fish.

As expected, the majority of entrainment for the 24-hour samples occurred at night with 70% and 79% of total entrainment at the north and south culverts, respectively. This is consistent with other studies on diel patterns of fish entrainment. In a study of entrainment at a delta agricultural diversion, Nobriga et al. (2004) found significantly higher entrainment during night and crepuscular periods for four species of open-water fishes (delta smelt, striped bass, threadfin shad *Dorosma petenense*, and inland silverside). Gaines and Martin (2001) observed relative abundance of Chinook salmon passing the Red Bluff Diversion dam to be greater for nocturnal periods (71-74%) than diurnal periods (26-29%).

A substantial portion of observed entrainment occurred during periods when the system was in 'drain only' mode (Figures 2 and 3). In drain-only mode, water is not diverted for waterfowl management. However, for this study the gates were opened and water was diverted for sampling purposes. In 2005, the highest fish catches were during a 'drain only' period. In 2006, the diversions were set on 'drain only' mode twice during the sampling season to prevent levee overtopping due to extremely high flows. Substantial fish catches occurred during these periods. Under normal operations, MIDS is often closed or diverting very little during spring when young fish numbers increase in the slough. Therefore, it appears that the existing MIDS operations actually provide some protection against entrainment of spring-spawning and spring-migrating fish, particularly open-water fish like delta smelt that do not aggregate around in-stream structures such as diversions.

The purse seine sampling suggested that most commonly entrained fishes also were common in GYS: threespine stickleback (74% in 2005; 39% in 2006) and prickly sculpin (11% in 2005; 16% in 2006). This is consistent with more than 20 years of otter trawling conducted in the Slough (Matern et al 2002). Delta smelt and Chinook salmon were rarely collected in GYS; steelhead were not collected, suggesting these species do not use this region of Suisun Marsh extensively. This is also consistent with long-term monitoring in Suisun Marsh; only 13 delta smelt were reported from GYS during 1984-2002, and only two Chinook salmon have been collected since 1979 (Matern et al 2002; Schroeter and Moyle 2004).

The generally low delta smelt numbers in GYS found historically (Matern et al. 2002), and during our study, are likely due primarily to high salinity. The population center for juvenile delta smelt in the San Francisco Estuary occurs at a surface specific conductance of about 2,000 µS/cm (2 mS/cm) (Figure 6). Average specific conductance for larval delta smelt is even lower, 0.5 mS/cm (Nobriga 2002). Figure 7 shows the monthly Progressive Daily Mean[1] (PDM) specific conductance for water quality monitoring station S-35 for water years 1985-2004 and two delta smelt surface conductivity reference points. The specific conductance values recorded in GYS over the past 20 years have always been higher than the average inhabited by larval delta smelt. In addition, more than 90% of the time the PDM was too high for the juvenile delta smelt population center to be near MIDS.

Delta smelt also mainly inhabit embayments and large channels rather than smaller marsh channels like GYS. Two possible exceptions to this generality are spawning adults and hatch-up larvae which may utilize marsh channels to greater extent than other life stages (Moyle 2002). However, delta smelt spawner distributions only encompass western Suisun Marsh in wet years (Hobbs et al. 2005). Delta smelt larvae likewise mainly occur in tidal fresh water (Nobriga 2002; Dege and Brown 2004), but the consensus among Interagency Ecological Program delta smelt biologists is that the larvae quickly become pelagic and occur mainly in large open-water habitats, where they spend most of the rest of their lives. To date, the only location delta smelt have ever been reported to be entrained in high numbers in Suisun Marsh is the Roaring River diversion (Pickard et al. 1982). However, as noted above, this is the largest diversion in Suisun Marsh. Further, it diverts water from Montezuma Slough, which is the largest channel in Suisun Marsh and connected on both sides to the

1. Progressive daily mean is the average of the specific conductance measurements made at the peak of all high tides from the beginning of the month to the day of interest. PDM is reset at the beginning of each month. At the end of the month, PDM, monthly average of all the mean daily high tide values, and monthly average high tide specific conductance are all equal.

large open-water shoals of Suisun Bay and the lower Sacramento River that are frequented by delta smelt (Moyle et al. 1992; Bennett et al. 2002).

The Suisun Marsh serves as a migratory corridor for immigrating adult Chinook salmon and emigrating juvenile salmon (Moyle 2002). The low numbers of Chinook salmon found in GYS are likely a result of its geographic location in the Marsh. All runs of Chinook salmon spawn in the Sacramento and/or San Joaquin Rivers. Culberson et al. (2004) used a coupled hydrodynamic-particle tracking model to assess the entrainment risk at MIDS for particles released at various locations in the estuary. Model runs found the entrainment risk for neutrally buoyant particles released in the Sacramento River near Rio Vista was less than 0.1%. This suggests that a juvenile salmon emigrating from the Sacramento River has a very low probability of being entrained at MIDS unless it swam into GYS; however, the low number of salmon caught during our study and during the long-term monitoring conducted by UCD suggests juvenile Chinook do not often make their way into GYS.

GYS is a marginal, rarely used habitat for special-status fishes. Fish screens are expensive to install and maintain, and evidence suggests that diversions in backwater areas such as Suisun Marsh have low or no impact on fish populations (Moyle and Israel 2005). Thus, based on the data collected at the intake and in GYS, screening MIDS would likely have negligible benefits to sensitive fish populations.

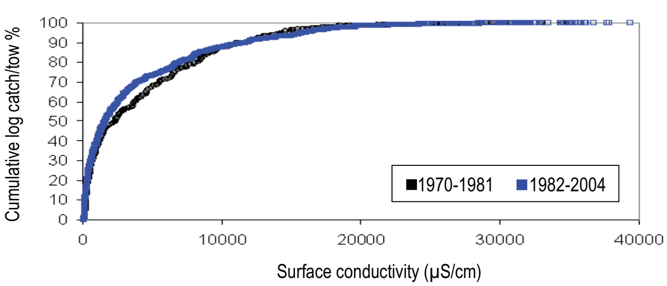

Figure 6 Percent delta smelt catch vs. surface conductivity in the San Francisco estuary. Note the x-axis is in ?S/cm. We have used mS/cm in the text; x-axis values must be divided by 1,000 to equal mS/cm

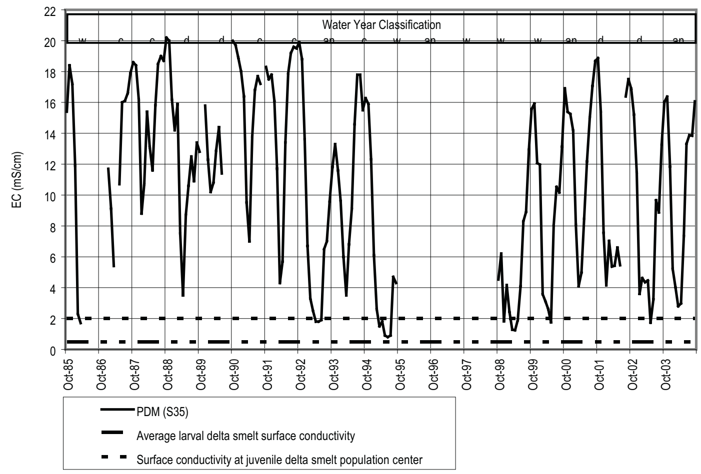

Figure 7 GYS historical salinity and delta smelt preferences

Acknowledgments

This study was conducted with the support of the Interagency Ecological Program. We thank B. McDonnell, V. Pacheco, and T. Sommer who facilitated IEP support. We thank all the DWR scientific aids and environmental scientists who spent many hours in the cold and dark for their field support; and Z. Maticia and R. Beckwith for assistance in equipment design. We gratefully acknowledge B. Tom for his assistance in intake flow modeling and purse seine volume calculation.

References

Bennett, W.A., Kimmerer, W.J., Burau, J.R. 2002. Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone. Limnology and Oceanography, 47(5):1496-1507.

California Department of Fish and Game [DFG]. 2007. Suisun Marsh atlas. Available at: http://www.delta.dfg.ca.gov/suisunmarsh/charter/atlas_documents/screened%20diversion%20flooding.pdf

Cook, L. and Buffaloe, L. D. 1998. Delta agricultural diversion evaluation summary report, 1993-1995. Interagency Ecological Program for the San Francisco Bay/Delta Estuary Technical Report 61. Sacramento, California.

Culberson, S.D., Harrison, C.B., Enright, C., Nobriga, M.L. 2004. Sensitivity of larval fish transport to location, timing, and behavior using a particle tracking model in Suisun Marsh, California. American Fisheries Society Symposium, 39:257-267.

Dege, M., and Brown, L.R.. 2004. Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco Estuary. American Fisheries Society Symposium 39: 49-65.

Gaines, P.S. and Martin, C.D. 2001. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River. Red Bluff Research Pumping Plant Report Series, Volume 14. U.S. Fish and Wildlife Service, Red Bluff, CA.

Herren, J.R. and Kawasaki, S.S. 2001. Inventory of water diversions in four geographic areas in California's Central Valley. Pages 343-355 in R. L. Brown, editor. Contributions to the biology of Central Valley salmonids. Volume 2. California Department of Fish and Game, Fish Bulletin 179, Sacramento California.

Hobbs, JA, Yin, Q-Z, Burton, J, Bennett, WA. 2005. Retrospective determination of natal habitats for an estuarine fish with otolith strontium isotope ratios. Marine and Freshwater Research 56:655-660.

MacFarlane, R.B., and Norton, E.C. 2002. Physiological ecology of juvenile Chinook salmon (*Oncorhyncus tschawytscha*) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California. Fishery Bulletin 100:244-257.

Matern, S.A. and Moyle, P.B. 1994. Trends in fish populations of Suisun Marsh: January 1992-December 1993. Annual report to California Department of Water Resources.

Matern, S.A., Moyle, P.B., and Pierce, L.C. 2002. Native and alien fishes in a California estuarine marsh: twenty-one years of changing assemblages. Transactions of the American Fisheries Society, 131:797-816.

Matica, Z, and Nobriga, M.L. 2005. Modifications to an agricultural water diversion to permit fish entrainment sampling. California Department of Fish and Game 91(1):53-56.

Meng, L., Moyle, P.B, Herbold, B. 1994. Changes in abundance and distribution of native and introduced fishes of Suisun Marsh. Transactions of the American Fisheries Society, 123:498-507.

Meng, L. and Matern, S.A. 2001. Native and introduced larval fishes of Suisun Marsh, California: the effects of freshwater flow. Transactions of the American Fisheries Society, 130:750-765.

Moyle, P.B., Herbold, B., Stevens, D.E., Miller, L.W. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society, 121:67-77.

Moyle, P.B. 2002. Inland fishes of California. University of California Press. Berkeley, California. 502 p.

Moyle, P.B. and Israel, J.A. 2005. Untested assumptions: effectiveness of screening diversions for conservation of fish populations. Fisheries, 30:5.

Nobriga, M.L. 2002. Larval delta smelt diet composition and feeding incidence: environmental and ontogenetic influences. California Fish and Game 88(4):149-164.

Nobriga, M.L., Matica, Z and Hymanson, Z.P. 2004. Evaluating entrainment vulnerability to agricultural irrigation diversions: a comparison among open-water fishes. American Fisheries Society Symposium 39:281-295.

Pickard A., Baracco A, Kano R. 1982. Occurrence, abundance, and size of fish at the Roaring River Intake, Suisun Marsh, California during the 1980-81 and the 1981-82 diversion seasons. IEP Technical Report 3. 14 p.

Schroeter, R. E. and Moyle, P.B. 2004. Trends in fish populations of Suisun Marsh: January 2003 – December 2003. Department of Wildlife, Fish, and Conservation Biology, University of California at Davis. Annual Report to the California Department of Water Resources.

[SEW] Suisun Ecological Workgroup. 2001. Final Report to the State Water Resources Control Board. California Department of Water Resources Report. Sacramento, CA. 271 p.

Notes

S. Chappell (Suisun Resource Conservation District). Personal correspondence with the senior author on January 11, 2007.