Comparison of Relative Abundance of Adult Chinook Salmon (*Oncorhynchus tshawytscha*) in the Delta Cross Channel, Georgiana Slough, and Sacramento River, California 2001.

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Introduction

Water from the Sacramento-San Joaquin Rivers and Delta is transported throughout California's Central Valley for irrigation and municipal use. The Delta Cross Channel (DCC) was constructed in 1951 to assist in transferring fresh water from the Sacramento River across the Delta (DWR 1993). Flow from the Sacramento River into the DCC is controlled by two radial arm gates located at the Sacramento River end of the DCC. These gates can be opened and closed depending on water quality, flood protection, and fish protection requirements.

Adult Chinook salmon (*Oncorhynchus tshawytscha*) are known to use the Sacramento River, DCC, and Georgiana Slough as migration pathways (Hallock *et al.* 1970). When the DCC gates are open, Sacramento River water is diverted into the Mokelumne and San Joaquin Rivers. Juvenile salmonids imprint on natal waters prior to and during emigration, allowing them to return to their stream of origin as adults (Hasler and Scholz 1983, Dittman *et al.* 1994). Therefore, some adult Chinook salmon returning to the Sacramento River system may be attracted into the San Joaquin and Mokelumne Rivers by diverted Sacramento River water, possibly increasing the chance of straying or delayed migration (since using either or both of these rivers is less direct than the Sacramento River). It is also possible that migrating adults using the DCC could be blocked if the DCC gates are closed after the fish have been attracted into the DCC. Major delays in migration, blocked passage, or straying of adult Chinook salmon could negatively affect spawning success. For example, prespawning mortality, straying, and gamete degeneration may increase when access to natal spawning areas is delayed or blocked. If this is the case, changes in DCC gate operations could affect the spawning success and therefore overall survival of Sacramento River Chinook salmon.

To assess possible effects of DCC gate operations on migrating adult Chinook salmon, the U.S. Geological Survey (USGS), U.S. Bureau of Reclamation (USBR), California Department of Fish and Game (DFG), and the U.S. Fish and Wildlife Service (FWS) collaborated on a pilot study in 2000. The purpose of this pilot study was to compare abundance and migration timing of adult Chinook salmon in the Sacramento River, DCC, and Georgiana Slough with the DCC gates open and closed using hydroacoustic, sonic tagging, and fyke trap data. The pilot study was expanded in 2001 by increasing sampling effort and duration. This report summarizes the FWS component of the 2001 collaborative study by testing for differences in relative abundance of adult Chinook salmon among the Sacramento River, DCC, and Georgiana Slough using fyke trap data.

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Methods

Sampling was conducted on the Sacramento River, within the DCC, and within the Georgiana Slough (Figure 1). To capture adult salmon, seven fyke traps were set among the three study sites. The Sacramento River fyke traps were placed above the DCC junction (Figure 2). One trap was fished approximately 200 meters upstream of the town of Locke on the east side of the river. The second trap was also placed on the east side of the river, near Vorden Road. Three traps were placed in the DCC, two just downstream of the gates on the north and south side, and one approximately 250 meters downstream of the gates (Figure 3). Two traps were placed on the west side of Georgiana Slough, approximately 500 and 1,000 meters north of the Tyler Island Bridge (Figure 4).

Fyke traps were 7.3 m long and 3.0 m in diameter (Figure 5). Each fyke trap consisted of two internal funnels made out of chain link fencing material and ending in steel rings. The funnels were surrounded by chain link fencing material and supported with wood reinforcements. The large end (3 meters in diameter) of both funnels faced one end (the mouth) of the trap. Fish were guided by the funnels into the other end of the trap and were removed with dip nets through an access panel.

Traps were transported on trailers, and deployed and retrieved with an electrical winch mounted to a truck. To place traps for sampling, each trap was rolled down the bank into the channel, submerged in at least three meters of water, and then anchored. To collect fish moving upstream, traps were set parallel to the flow, with the mouth facing downstream. Traps were checked by pulling the trap partially out of the water, opening the access panel, and using a dip net to remove any captured fish.

Sampling began on 4 September and continued through 15 November 2001. This time frame coincides with the immigration of adult fall Chinook salmon (Hallock and Fry 1967). In general, traps were checked daily and fished four days per week. Traps were deployed on Monday mornings and removed Friday mornings. Fish captured in the traps were identified to species and fork length was measured to the nearest 5mm. Fork lengths for larger fish (greater than 500mm) were estimated to the nearest 5mm to reduce handling time and therefore handling stress. Set times and retrieval times, general weather conditions, and water temperature in degrees Fahrenheit were recorded when each trap was set and checked.

To assess recapture rates, some fish were tagged with Floy® tags. Minimum size for tagging fish varied by species. Chinook salmon over 500mm were tagged (unless used in the DFG sonic tagging study), striped bass (*Morone saxatilis*) over 420mm were tagged, and *Micropterus* species over 300mm were tagged. Steelhead trout (*O. mykiss*) and Sacramento splittail (*Pogonichthys macrolepidotus*) were not tagged. Other fish were tagged if over 200mm. Most fish were released immediately after processing. Some of the adult salmon captured in the fyke traps were used by DFG for the sonic tagging component of the study.

To determine if captures of Chinook salmon differed between fyke traps set in the same study area, the numbers of Chinook salmon captured for each trap were compared using the log-likelihood ratio (Zar 1984). Because all traps were not deployed on the same day, only capture data when all traps were fishing were used in the log-likelihood analysis. To compare relative abundance of Chinook salmon among the study sites, data were standardized to account for different effort (*i.e.*, numbers of traps differed between location) and different channel sizes. To do this, we estimated daily relative abundance of Chinook salmon by expanding the catch per unit effort (catch/m^2) from each fyke trap times the cross sectional area of the river using the following equation:

$$RA = (C_s / P_f) * (M_d / M_f)$$

Where:

$$P_f = A_t / A_c$$

And:

RA	=	daily relative abundance
C_s	=	number of salmon captured during the time (in minutes) the trap was deployed
P_f	=	proportion of the channel cross section that was fished by each fyke trap.
A_c	=	estimated cross sectional area of each river or slough channel (obtained from Jon Burau, USGS, Sacramento, CA, personal communication)
A_t	=	area of the mouth of each fyke trap (fully submerged)
M_d	=	number of minutes in a 24-hour day
M_f	=	number of minutes trap was actually fishing (*i.e.*, traps were not set and checked in exact 24-hour intervals, so we standardized for actual time the trap was deployed).

Expansions of trap catches were based on proportion of channel fished because no data on trap efficiency were available (Dave Kohlhorst, DFG, Stockton CA, personal communication). Estimates of daily relative abundance did not meet assumptions of parametric statistics, so differences among estimated daily relative abundances were determined using the Kruskal-Wallace test. Pair-wise comparisons to examine the relative differences between study locations were made using nonparametric Tukey-type multiple comparison procedure for unequal sample sizes (Zar 1984).

Results

In 262 total trap days, 1,233 fish were captured, divided among 21 species (Table 1). Captures of Chinook salmon were low in all three locations, with an overall total of 155 Chinook salmon captured. Most of the Chinook salmon captured were observed in the Sacramento River (n = 80). Fifty-three Chinook salmon were captured in Georgiana Slough. Despite additional trapping effort (*i.e.*, three traps in the DCC and two traps in the other locations), captures of adult Chinook salmon were lowest in the DCC (n = 22). Eleven adult Chinook salmon were Floy® tagged in the DCC, 41 were tagged in Georgiana Slough, and 62 were tagged in the Sacramento River. None of these Floy® tagged adult Chinook salmon was recaptured in the traps.

The log-likelihood ratio showed no significant difference between numbers of Chinook salmon captured among traps located in the DCC ($G = 5.940$, $p= 0.052$) or Georgiana Slough ($G = 0.170$, $p> 0.50$). Catches were significantly different between traps set in the Sacramento River ($G = 23.19$, $p < 0.001$), with the upstream trap catching more Chinook salmon than the downstream trap (61 compared to 19). Because of the variability associated with catches in fyke traps (D. Kohlhorst, personal communication) and similar gear (Hubert 1996), estimated daily relative abundance was calculated per trap and these individual estimates were used to compare daily relative abundance among location.

Estimates of daily relative abundance ranged between 0 and 765 (Table 2). Of the 262 trap days, 170 (65 percent) had estimated relative abundances of zero. Despite the high level of variation, significant differences in estimated daily relative abundance were found among all three locations. Estimates of daily relative abundance were lower in the DCC compared to both the Sacramento River ($q = 7.11$, $p < 0.001$) and Georgiana Slough ($q = 3.44$, $p < 0.002$), and estimates of daily relative abundance were lower for Georgiana Slough compared to the Sacramento River ($q = 6.44$, $p < 0.001$).

Discussion

Available literature suggests that net construction (*e.g.*, mesh size, size of mouth, size of funnel openings) and deployment (*e.g.*, distance from shore, water depth) as well as physical variables (*e.g.*, habitat, water temperature, turbidity, season) can have significant effects on catch per unit effort for entrapment gears (see Hubert 1996 for summary). These variables often are not related to population size, making it difficult to estimate population size from capture numbers. For this reason, population estimates from passive gears are frequently derived from some type of mark-recapture method (Ricker 1975).

In addition, estimates of daily relative abundance were compromised by a variety of other factors. First, estimates were highly variable in all three locations. In addition, calculations of error around these estimates were compromised by low capture numbers for Chinook salmon (usually less than two per day, with many trap days with no captures), lack of data on the effectiveness of fyke traps (*i.e.*, efficiency of this gear), and variation in capture rates between fyke traps (at least in the Sacramento River).

Despite these limitations in the data, it appears that adult fall Chinook salmon use the DCC as an immigration corridor less than either Georgiana Slough or the Sacramento River. Adult fall Chinook salmon also appear to use Georgiana Slough less than Sacramento River. Implications from these preliminary findings are encouraging, since adult fall Chinook salmon returning to the Sacramento River to spawn could experience delays in migration if they use Georgiana Slough (rather than the Sacramento River) or the DCC, particularly if the DCC gates are closed.

We were unable to relate DCC gate operations to fyke trap catches for several reasons. First, the DCC gates were opened and closed frequently, throughout the study period (see Appendix A). Since trap intervals were approximately 24 hours, we were unable to determine the time of capture and whether or not that corresponded with the DCC gates being open or closed. The hydroacoustic data were intended to address abundance in relation to DCC gate operations since detection times were known. In addition, there is likely some lag time between attraction into the San Joaquin River, Mokelumne River, or DCC when the gates are open and the arrival of individual Chinook salmon at the DCC. The sonic tagging experiment should help address this situation. For these reasons, analyses of the sonic tagging data and hydroacoustic data are critical to understanding how DCC gate operations may affect migrating adult fall Chinook salmon.

Efficiency studies on fyke traps in this geographic area would be valuable since it is unlikely that fish are randomly distributed throughout the river channel or that fish do not (or cannot) avoid the fyke traps. Both of these assumptions are incorporated into the daily relative abundance estimate calculated in this report. It would also be beneficial to expand the sampling period so effects on other Chinook salmon runs could be assessed, although this would be problematic because it could necessitate handling adult Chinook salmon from listed species (*i.e.*, winter run and spring run Chinook salmon).

This study was designed as a component of a much larger study incorporating hydroacoustic data and sonic tagging of adult Chinook salmon; therefore, care must be taken in drawing conclusions from the fyke trap data in isolation. The main purpose of the fyke trap data was to help identify the species and proportions of fish observed during the hydroacoustic monitoring. The hydroacoustic data collected by the USGS were to be used to assess effects of DCC gate operations on adult Chinook salmon populations and differences in abundance between the DCC, Georgiana Slough, and the Sacramento River. To provide the species composition data in a format useful for analyzing the hydroacoustic data, additional information on sizes of fish detected and resolution (*i.e.*, differences in sizes that can be detected) of hydroacoustic data is needed.

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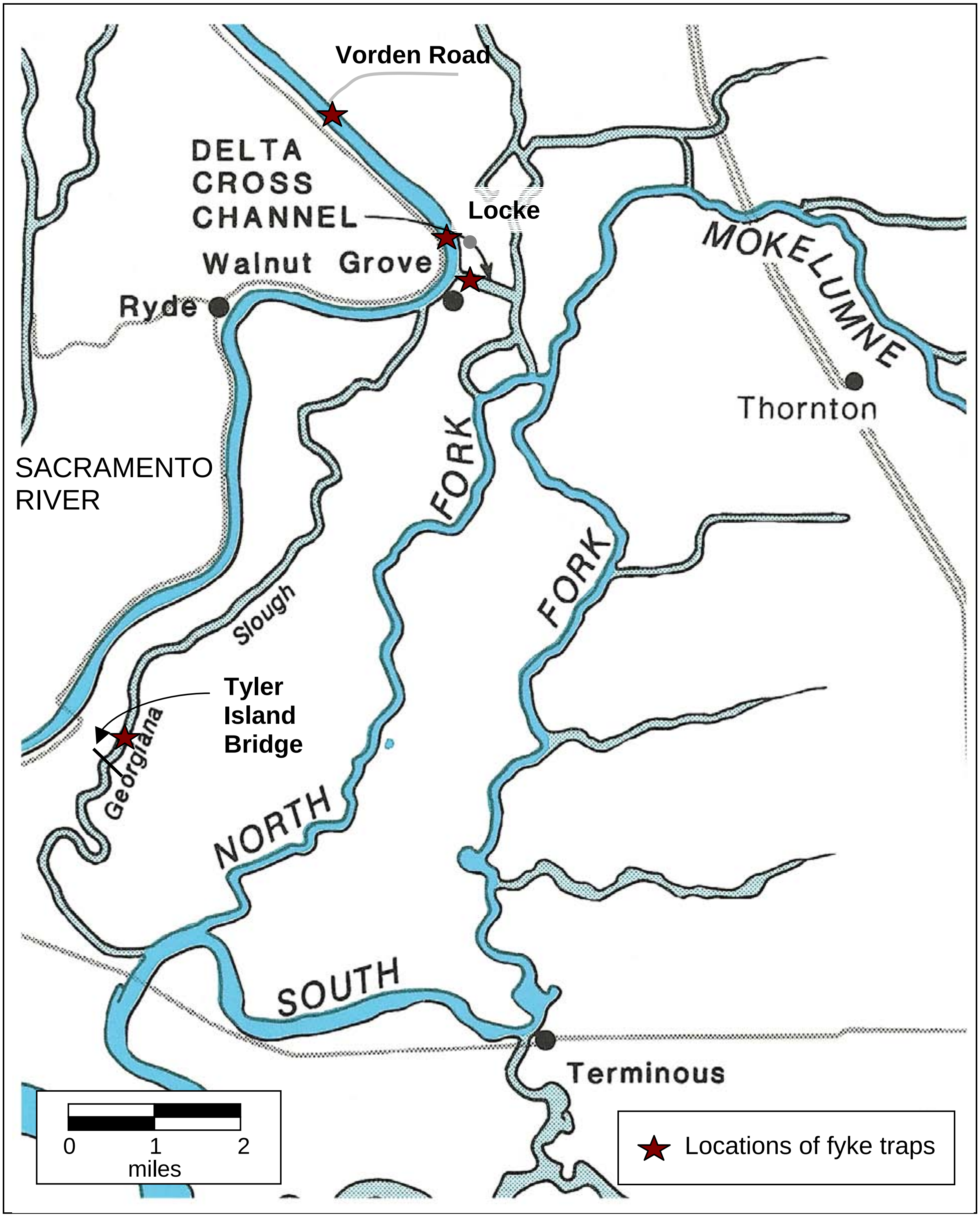

Figure 1. Map showing 2001 study area including the Delta Cross Channel, Georgiana Slough, and a section of the Sacramento River, California (adapted from DWR 1993).

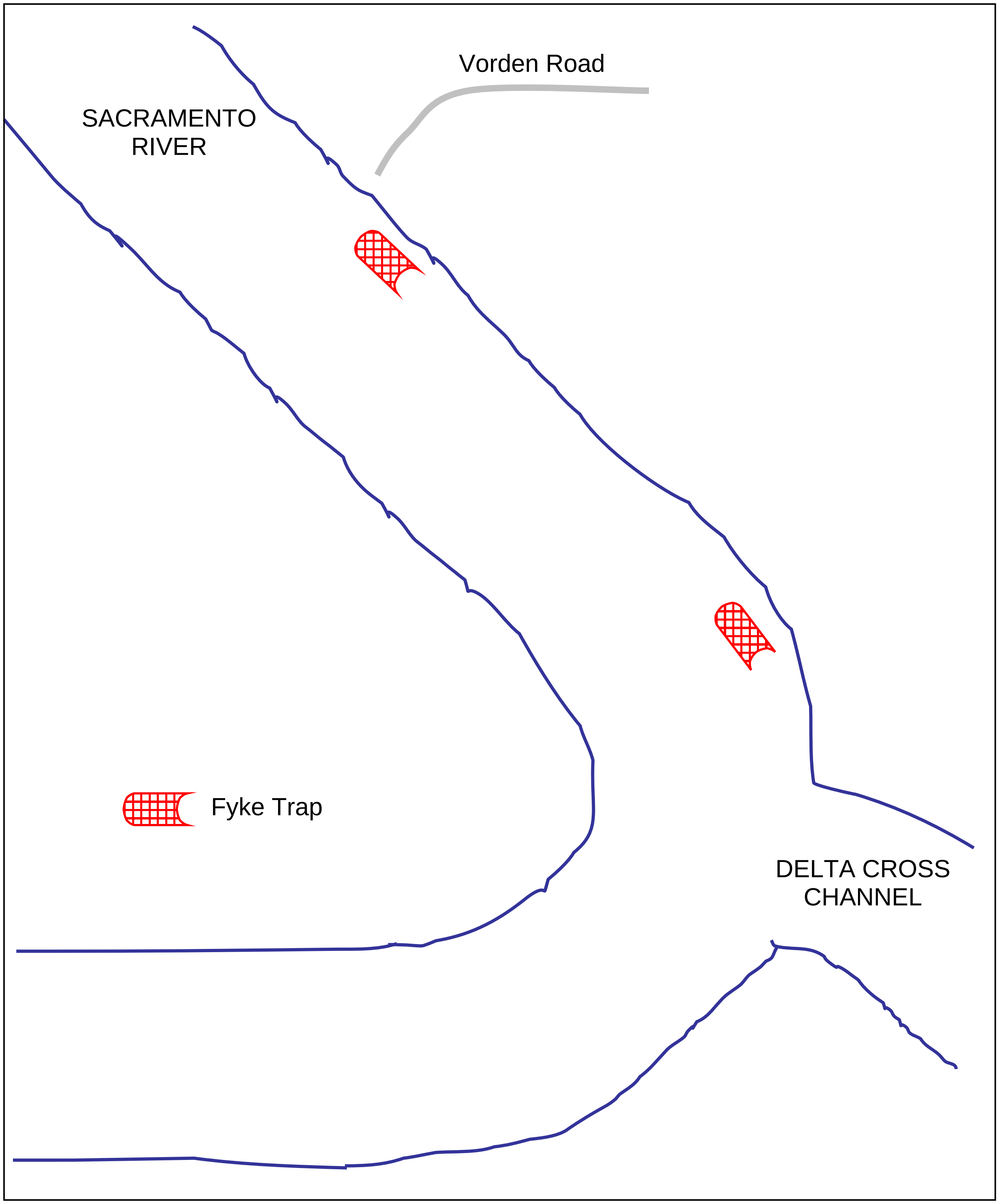

Figure 2. Schematic (not to scale) showing approximate locations and orientations of fyke traps in Sacramento River, California (4 September through 15 November 2001).

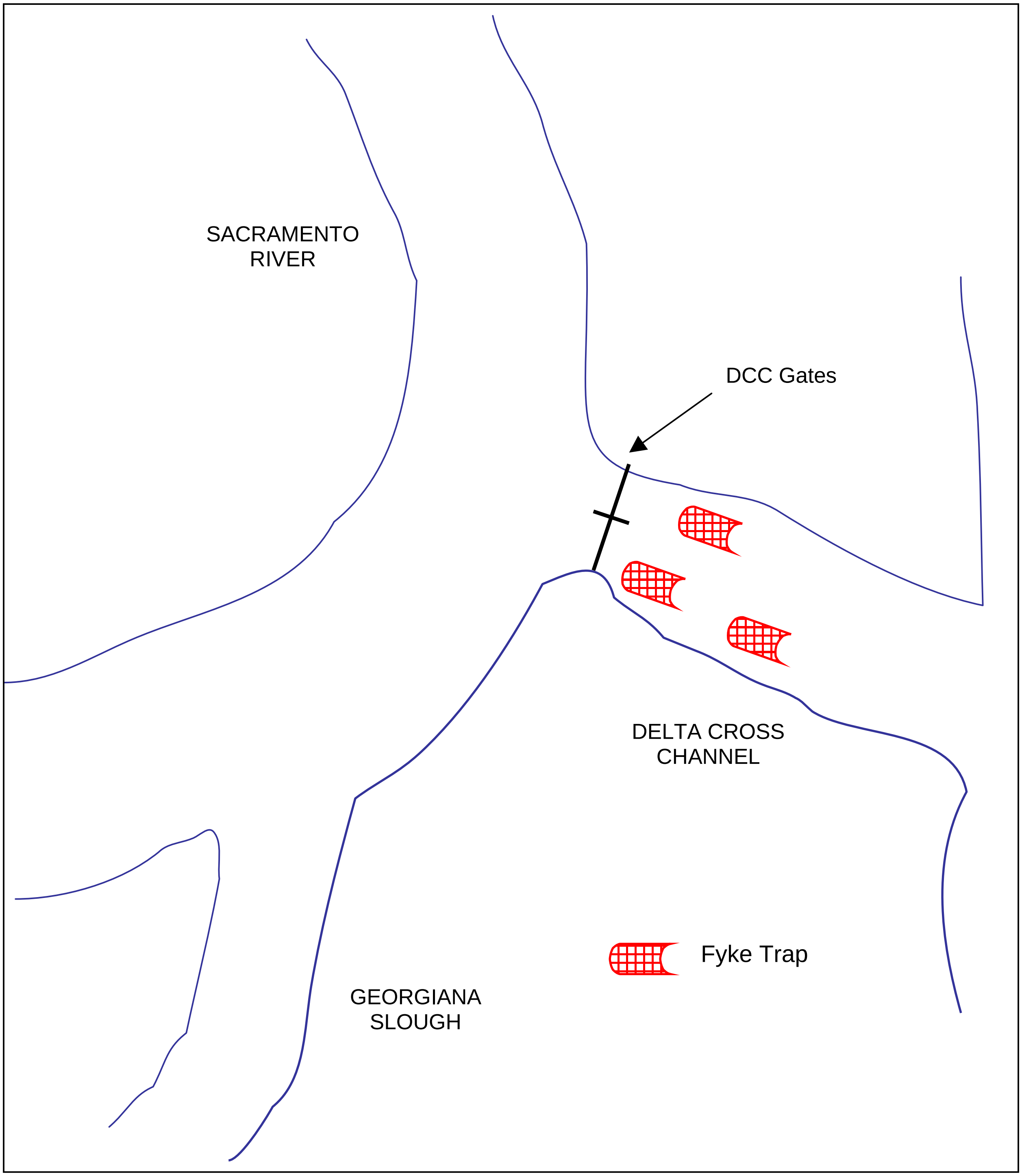

Figure 3. Schematic (not to scale) showing approximate locations and orientations of fyke traps in the Delta Cross Channel (DCC), California (4 September through 15 November 2001).

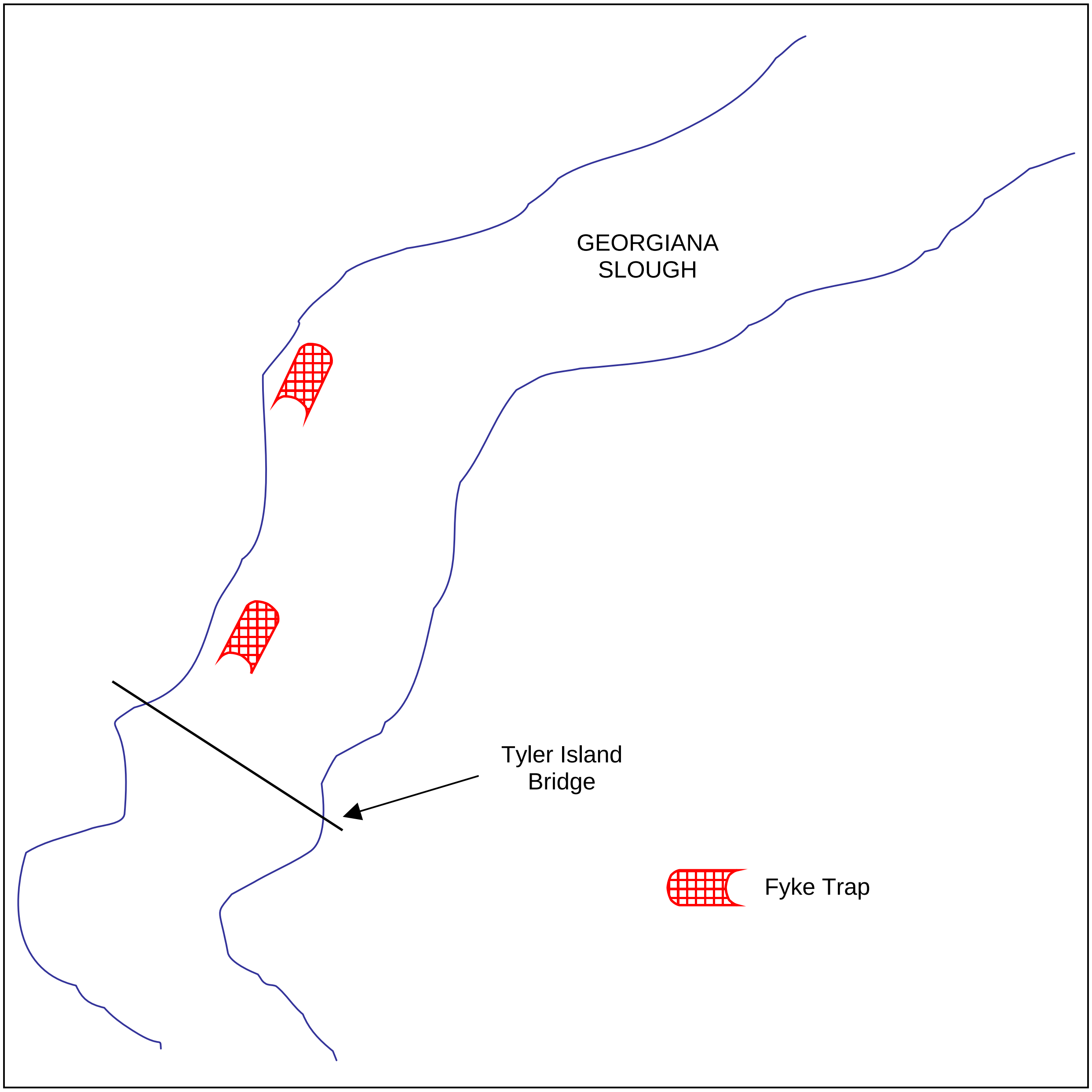

Figure 4. Schematic (not to scale) showing approximate locations and orientations of fyke traps in Georgiana Slough, California (4 September through 15 November 2001).

Figure 5. Picture of a fyke trap used to collect adult Chinook salmon (and other fish) in the Delta Cross Channel, Georgiana Slough, and Sacramento River, California (4 September through 15 November 2001).

Table 1. Numbers of fish caught in fyke traps by species in the Delta Cross Channel (DCC), Georgiana Slough (GS), and Sacramento River (SR), California, 4 September through 15 November 2001.

Location	Trap Days	Species	Number Captured
DCC	113	Black crappie	13
		Chinook salmon (unmarkedl[1])	22
		Largemouth bass	8
		Rainbow/Steelhead trout (unmarked[1])	5
		Rainbow/Steelhead trout (marked[1])	8
		Redear sunfish	22
		Smallmouth bass	30
		Spotted bass	22
		Striped bass	14
		Other species	10
		Total	154
GS	73	Carp	5
		Chinook salmon (unmarked[1])	47
		Chinook salmon (marked[1])	6
		Channel catfish	11
		Largemouth bass	15
		Rainbow/Steelhead trout (unmarked[1])	3
		Rainbow/Steelhead trout (marked[1])	9
		Redear sunfish	79
		Sacramento sucker	14
		Smallmouth bass	75
		Spotted bass	30
		Striped bass	63
		White catfish	11
		Other species	9
		Total	377
SR	76	Black crappie	10
		Chinook salmon (unmarked[1])	73
		Chinook salmon (marked[1])	7
		Largemouth bass	9
		Rainbow/Steelhead trout (unmarked[1])	7
		Rainbow/Steelhead trout (marked[1])	9
		Redear sunfish	86
		Sacramento pikeminnow	8
		Sacramento sucker	21
		Smallmouth bass	270
		Spotted bass	35
		Striped bass	131
		White catfish	19
		White crappie	7
		Other species	10
		Total	702

[1] Marked fish have adipose fin clips and may or may not have coded-wire tags and are considered to be hatchery origin. Unmarked fish do not have either of these marks and may be hatchery or natural origin.

Table 2. Number of trap days per location, minimum, maximum, and mean estimated daily relative abundance for adult Chinook salmon captured in the Delta Cross Channel (DCC), Georgiana Slough (GS), and Sacramento River (SR), California, 2001.

		Estimate of Daily Relative Abundance		
Location	# trap days	Minimum	Maximum	Mean (SD)
DCC	113	0	208	14 (39.8)
GS	73	0	140	24 (31.3)
SR	76	0	765	118 (161.6)

Appendix A. Date operations for the Delta Cross Channel between 4 September and 15 November 2001. Times are approximate and refer to when the described action began. Gate actions may take up to 30 minutes to complete (source: DCC gate operational log, USBR Central Valley Operations Office, Water Operations Division, Sacramento, California).

Date(s)	Time	Action	Remarks
09/04/01 - 10/08/01		open	
10/08/01	0645	closed	Begin study to determine how best to operate DCC gates to protect fish and water quality.
10/08/01	1225	open	
10/09/01	0739	closed	
10/09/01	1325	open	
10/10/01	0824	closed	
10/10/01	1410	open	
10/11/01	2024	closed	
10/12/01	0125	open	
10/12/01	2119	closed	
10/13/01	0235	open	
10/13/01	2204	closed	
10/14/01	0335	open	
10/14/01	2304	closed	
10/15/01	0425	open	
10/16/01	0038	closed	
10/16/01	0514	open	
10/17/01	0154	closed	
10/17/01	0615	open	
10/18/01	0249	closed	
10/18/01	0820	open	
10/19/01	0404	closed	
10/19/01	0920	open	
10/20/01	0459	closed	
10/20/01	1030	open	
10/20/01	1518	closed	
10/20/01	2035	open	
10/21/01	1605	closed	
10/21/01	2134	open	
10/22/01	1700	closed	
10/22/01	2206	open	
10/23/01	1735	--	Gate was supposed to be closed, operator missed the closure.
10/24/01	1852	closed	
10/24/01	2359	open	
10/25/01	2004	closed	
10/26/01	0054	open	
10/26/01	2030	closed	
10/27/01 – 11/15/04	0139	open	End DCC gate operation study, gate left open.