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Predicting juvenile Chinook Salmon routing in riverine and tidal channels of a freshwater estuary

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Abstract As juvenile salmonids migrate from natal streams to the ocean they can encounter junctions leading to migration routes that differ in quality and survival probability, including: side channels, agricultural diversions, floodplains, cooling intakes and turbines. Although juvenile salmon are known to use all these routes, it is often difficult to estimate what proportion of migrants may use each. Managers would benefit from knowledge of how hydrologic manipulation (e.g., dam releases, water diversions) can reduce exposure to unfavorable routes and keep more fish in higher survival routes. We assembled 41 estimates of juvenile salmon routing at six junctions in the Sacramento-San Joaquin Delta to test the ability of three hydrologic metrics to predict fish routing at distributary channels. The proportion of flow entering the distributary was selected as the best predictor and explained 70 % of observed variation in fish routing. This linear model was then used to predict routing at nine junctions under various combinations of inflow and exports. Our results suggest that more fish enter distributaries at junctions with strong riverine influence, whereas at tidally dominated junctions entrainment was lower. River inflow had the largest effect on entrainment at the two riverine-dominated junctions, although confidence intervals overlapped over the range of flows. Exports had a smaller than expected effect, but had the greatest effect at junctions directly connected to the channels with water diversions. These results suggest that flow proportion is an effective metric to predict fish routing. However, results also suggest it may be difficult to appreciably alter fish routing by manipulating river inflows or water diversions.

Keywords Hydrodynamics · Flow · Routing · Salmon · Sacramento-San Joaquin Delta · Estuary · Tides · Behavior · Water diversions

Introduction

Juvenile anadromous salmonids travel great distances from spawning habitat in freshwater rivers to the ocean, sometimes located hundreds of kilometers away. As juveniles migrate downstream from natal streams to the ocean, they encounter a variety of different migration pathways and rearing habitats. Some of these pathways may be advantageous, such as productive floodplains and side channels that may enhance growth (Sommer et al. 2001; Jeffres et al. 2008; Bellmore et al. 2013). Others may lead to habitats with greater risks of mortality such as agricultural diversions, turbines, industrial cooling systems, or habitats with high predator abundance (Roberts and Rahel 2008; Buchanan et al. 2013). Although patterns of habitat use have been relatively well reported (Brandes and McLain 2001), it has been more difficult to estimate the proportion of a population that is exposed to entrainment into alternative routes (Post et al. 2006; Carlson and Rahel 2007).

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Anadromous salmonids in California's Central Valley have experienced considerable declines in the last 50 years, with three populations listed as threatened or endangered, and routine restrictions of commercial and recreational fisheries (Lindley et al. 2009). Juveniles of Central Valley salmonid populations migrate through the Sacramento-San Joaquin Delta (Delta) on their way to the Pacific Ocean. This region is a complex array of freshwater riverine and tidal channels that have been subject to intense water development, land use changes and non-native species introductions, which have impacted the ecosystem at multiple trophic levels (Sommer et al. 2007). The main stem river channels have been identified as migration routes with the best survival rates for juvenile salmonids, whereas distributary channels lead to a network of channels where survival is lower and fish are in closer proximity to large water diversions (Kimmerer 2008; Newman and Brandes 2010; Perry et al. 2010).

Kemp et al. (2005) analyzed the behavior of salmon smolts in a flume and observed that most selected a route in a ratio consistent with flow proportion. When flows were constricted within one of the flume channels, they observed smolts detecting and avoiding accelerating flow. At the macro-scale, Steel et al. (2013) analyzed Chinook salmon routing in relation to factors such as velocity, flow direction, channel position and migration speed. They found the ratio of mean velocity in the main stem and distributary channel was the strongest predictor, but conducted their analysis only at a single junction with strong riverine influences (and minimal tidal influence).

Conservation efforts in the Delta have focused on managing inflows, exports, gates and non-physical migration barriers (e.g. Perry et al. 2013) because these actions can to varying degrees reduce the proportion of fish entering less favorable routes. However, survival in some routes remains very low (Buchanan et al. 2013). Thus, resource managers are in need of tools that can predict how fish movement into alternative migration routes is influenced by water management actions (inflows and exports) relative to those not under management control (tides). Currently, more exports are assumed to increase entrainment into distributary routes and more inflow is assumed to keep fish in main channel routes. However, there has not been a quantitative analysis of how either of these drivers actually influence routing of juvenile salmonids across the full range of riverine and tidal conditions that occur in the Delta.

Here we propose a conceptual basis for predicting fish routing across a broad range of physical and hydrodynamic conditions. We test predictions of our conceptual model against empirical observations available for the Delta. Lastly, we assess how fish routing can be expected to change as a result of river inflows and water diversion management. The diverse channel morphologies and hydrodynamic drivers of the Delta provide a unique setting for developing and testing such a model; the results provide resource managers with quantitative predictions for effectiveness of proposed management actions.

Methods

Study area

The Delta is the furthest upstream region of the San Francisco Estuary, located at the confluence of the Sacramento River, the San Joaquin River and several smaller tributaries (Fig. 1). The Delta collectively drains≈40 % of the surface area of California and is primarily freshwater; however, salinity can vary in the downstream areas in response to seasonal variations in freshwater input and spring-neap tidal cycles (Nichols et al. 1986).

The Delta is part of the largest estuary on the west coast of North America and is unusual for its "inverted" geology. In contrast with a normal delta, an "inverted" delta begins with a network of channels (resulting from the convergence of Sacramento and San Joaquin Rivers in this case) and ends with a single channel leading to the ocean. The network of bifurcated channels occurs along a gradient of riverine to tidal influence, providing a unique setting for evaluating factors influencing migratory fish routing.

The Sacramento and San Joaquin Rivers are the primary migration corridors utilized by anadromous salmonids on their way to and from upstream tributaries in the Central Valley. Distributaries of both rivers form noncontiguous areas of tidal and riverine channels referred to as the interior Delta (Fig. 1). Two large water diversions are located in the southern portion of the interior Delta and can divert up to 65 % of total inflow to the Delta in some circumstances (Sommer et al 2007). These diversions have been hypothesized to alter Delta hydrodynamics so that juvenile salmon are "pulled" from the main stem Sacramento and San Joaquin rivers

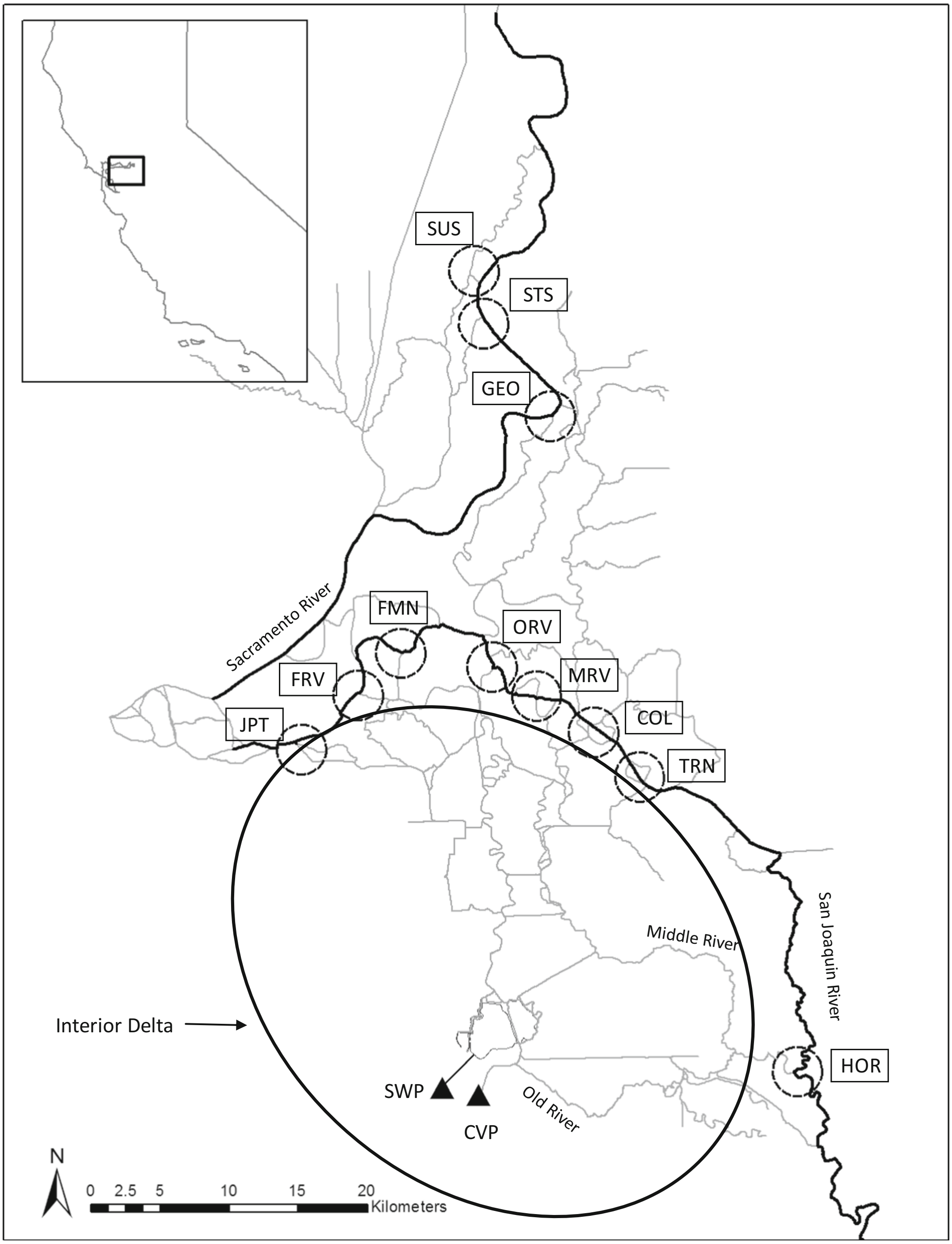

Fig. 1 Map showing the location of the Sacramento-San Joaquin Delta within California and the specific junctions examined in the current study. Abbreviations are as follows: SUS = Sutter Slough, STS = Steamboat Slough, GEO = Georgiana Slough, JPT = Jersey Point, FRV = False River, FMN = Fisherman's Cut, ORV = Old River, MRV = Middel River, COL = Columbia Cut, TRN = Turner Cut, HOR = Head of Old River. The triangles indicate the location of the State Water Project (SWP) and Central Valley Project (CVP) pumping facilities. Circled area indicates the interior Delta

into the interior Delta where survival is lower (NRC 2012; NMFS 2009). Here we consider the influence of three mechanisms on hydrodynamics at Delta junctions: 1) freshwater inflow, 2) tides, and 3) freshwater diversions. The relative importance of each factor can vary in time and space—making it difficult to provide general descriptions of Delta hydrology—and complicates predictions of how juvenile salmonids respond to water management.

Our investigation examined major distributary junctions leading from the main stem San Joaquin and Sacramento rivers into the interior Delta (Fig. 1). Though two junctions (Sutter and Steamboat Sloughs) are not junctions leading to the interior Delta, they are major junctions influenced by riverine and tidal effects for which fish routing observations were available.

Delta flow data

Due to the size and complexity of the Delta, field-measured flows were not available for studied locations. We instead relied upon simulations provided by the DSM2 Hydro model. DSM2 Hydro is a one-dimensional hydrodynamic model that simulates flows in the Delta's network of riverine and estuarine channels. For a given set of historic or simulated boundary conditions (tides, river inflows, and exports) the model provides stage, velocity and flow data at 15-min intervals for hundreds of channels in the Delta. The model has been calibrated to observed flow and stage data and validated by comparing simulated data with field data from a different time period (Kimmerer and Nobriga 2008). DSM2 Hydro has been extensively tested by the California Department of Water Resources and is used for planning and operation of the State Water Project and Central Valley Project water diversions. More detailed information about the DSM2 Hydro model can be found at: http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm.

For our analysis, we used DSM2 Hydro data from simulations of historic conditions and from a subset of scenarios and model runs specified and used by Kimmerer and Nobriga (2008). DSM2 Hydro simulations representing historic conditions were used to analyze acoustic telemetry data in relation to site-specific hydrodynamic conditions. Our assessment of how river inflow and freshwater diversion management might influence fish routing relied upon "base" model runs from Kimmerer and Nobriga (2008). These scenarios were not comprehensive, but represented the range of diversions and river inflows within operational control of water project managers (Table 2; Kimmerer and Nobriga 2008).

Junction hydrodynamics

Authors have previously analyzed fish routing behavior in relation to instantaneous junction velocities (e.g. Kemp et al. 2005; Steel et al. 2013). While such analyses may be reasonably predictive for the specific junctions studied, the approach has not provided a generalized basis for predicting fish routing at any junction, and particularly not for junctions where detailed fish-velocity observations are lacking. Our approach first defined a conceptual model describing factors likely to influence route selection of migrating juvenile fish (Fig. 2). Factors such as lateral position of fish in the channel, fish residence time at the junction, and fish arrival timing at the junction relative to tides likely influence routing to at least some degree. However, we hypothesized fish routing proportions could be at least coarsely predicted from hydrodynamic measurements at junctions over a 1 day period. This approach was supported by analyses of Holbrook et al. (2009) and Perry (2010), which found the proportion of acoustically-tagged fish diverted at two Delta junctions—from the San Joaquin River into Old River (HOR) and from the Sacramento River into Georgiana Slough (GEO), respectively—were roughly proportional to the volume of flow diverted at these junctions. However, both HOR and GEO are predominately influenced by river inflows and less by tides than many junctions occurring downstream. Thus,

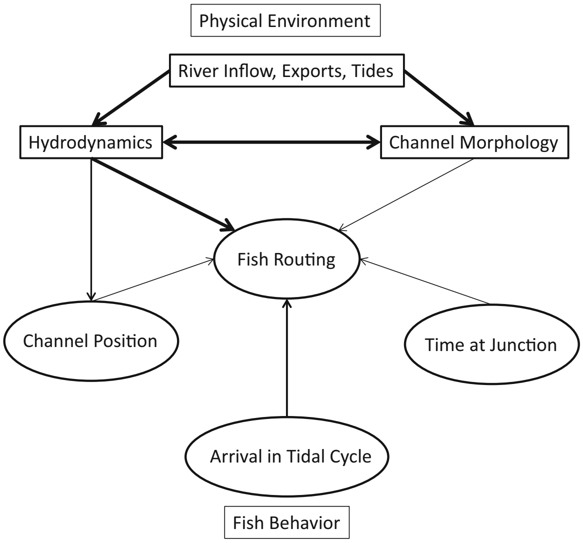

Fig. 2 Conceptual model of the physical and behavioral influences on the routing of juvenile salmonids at channel junctions. Line thickness indicates the hypothesized strength of each relationship based on the literature

neither Holbrook et al. (2009) or Perry (2010) tested or described a metric which could be applied at both tidal and riverine junctions.

In order to summarize hydrodynamic conditions influencing fish routing at Delta junctions, we estimated three metrics for each distributary route: 1) the proportion of flow entering the distributary, 2) the ratio of velocity in the main channel to velocity in the distributary and 3) the proportion of time that flow was entering the distributary. These data were estimated at 15-min intervals and summarized over 24 h. The analysis began with the construction of a schematic plan-view for each junction (Fig. 3). Channels entering and exiting the junction were labeled sequentially in a clockwise fashion. For calculation purposes, water, which flowed into a junction—when the direction of flow was toward the center of the junction—was termed "input" (I); water which flowed into the distributary route was termed "output" (O). At each 15-min time interval provided by DSM2 Hydro, the proportion of flow entering the distributary route (ρ) was calculated as:

$$\rho_{jt}=\frac{O_{jt}}{I_{jt}}$$

where O_{jt} is flow in $m^3\ s^{-1}$ entering the distributary route at junction j at 15-min time interval t, and where I_{jt} is the total inflow ($m^3\ s^{-1}$) entering from junction j channels at 15-min time interval t. Calculations were made with the following assumptions:

a) ρ_{jt} could not exceed 1.
b) When flow was entering the junction from the distributary channel, ρ_{jt} was set to zero.

To produce a daily metric, we calculated *total flow proportion* entering a distributary channel and/or the interior Delta (ρ_j) at each junction over 24 h; calculated as:

$$\rho_j=\sum_{t=1}^{96}\frac{O_{jt}/I_{jt}}{96} \tag{1}$$

In riverine junctions with primarily unidirectional flow, ρ_j can be approximated by a ratio of average daily flows. However, accounting for flow proportion at 15-min intervals is important for junctions with strong tidal influence.

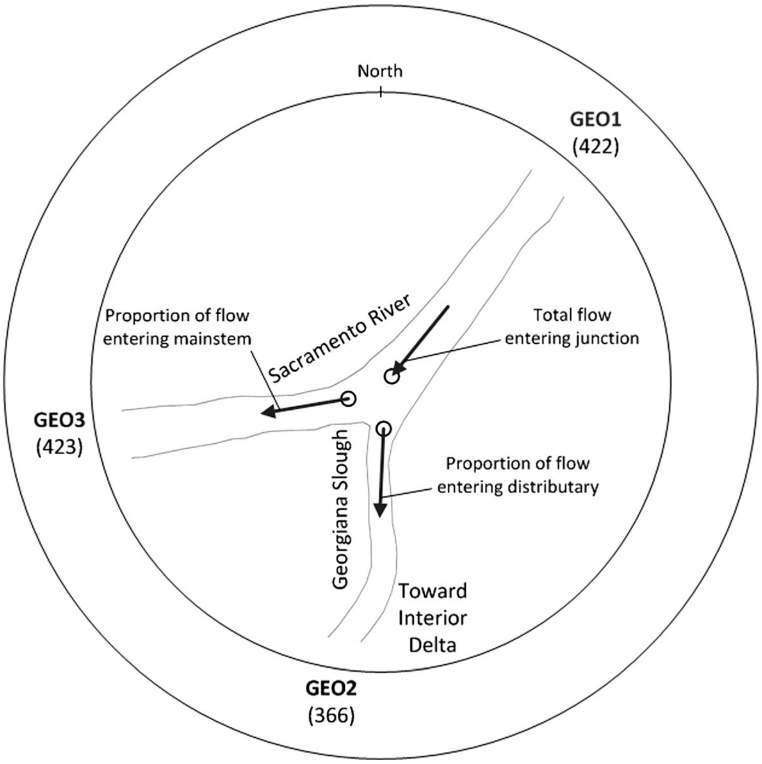

Fig. 3 Plan view of the junction of the Sacramento River and Georgiana Slough, showing DSM2 model nodes used in the calculation of the three hydrodynamic metrics used to model observed routing of juvenile Chinook salmon

The proportion of time flow entered the distributary was calculated as:

$$\delta_j = \frac{\sum_{t=1}^{96} (D_t > 0)}{96}$$

where δ_j is the proportion of time flow is entering the distributary, and D_t is flow in the distributary at each 15 min interval. The mean ratio of velocity in the main channel relative to velocity in the distributary was calculated as:

$$\gamma_j = \sum_{t=1}^{96} \frac{M_{jt}/D_{jt}}{96}$$

where γ_j is the mean velocity ratio, M_{jt} is the velocity in the main channel at junction j at time t and D_{jt} is the velocity in the distributary at junction j at time t.

Fish routing vs. hydrology

To examine the utility of hydrologic metrics to predict routing of juvenile salmon into distributary migration routes, an information theoretic approach was employed. Routing estimates from 41 independent release groups of acoustically-tagged juvenile Chinook salmon in the Delta were obtained from the literature (Table 1). These releases of tagged juvenile Chinook salmon included both fall and late fall run fish. Releases of fall run fish were performed in the San Joaquin River at two locations (Durham Ferry and the City of Stockton) during April and May. Late fall run fish were released near the City of Sacramento in December and January. The months of release corresponded to the respective outmigration period for each run. Three hydrologic metrics (described previously) were examined to determine how well they could predict observed juvenile Chinook salmon routing at junctions. Each hydrologic metric was calculated as an average over 7 days following the release. Michel et al. (2013) reported that on average, juvenile salmon migrated through the Delta in 6.5 days.

Three linear regression models were constructed in which the proportion of juveniles entering the distributary route was the response variable and one of the three hydrologic characteristics was the predictor variable. Models with more than one predictor could not be used due to multicollinearity. A Shapiro-Wilk test was used to test the assumption of normality and residual plots were used to assess homoscedasticity. Akaike's Information Criterion corrected for small sample size (AIC_c) was then calculated for each model. The difference in AIC_c between the best fit model and each candidate model was calculated (ΔAICc) and any model with a value<2.00 was considered to have similar predictive power (Burnham and Anderson 2002).

Fish routing sensitivity to water management

To assess how water management might influence fish routing, we used the best-fit linear regression model described above to predict fish routing at nine Delta junctions with nine different combinations of river inflow and South Delta water diversion (Table 2). Means and confidence intervals for each junction under the different flow diversion scenarios were then plotted. As described previously, these scenarios utilized "base" model runs from Kimmerer and Nobriga (2008).

Results

Observed fish routing

Model selection indicated that the proportion of flow entering a distributary was the best predictor of observed fish routing. No other model had a ΔAIC_c less than 22.3 (Table 3). The regression model that used total flow proportion explained 69.5 % of the variation in observed routing ($R^2=69.5$) from the 41 acoustically tagged juvenile Chinook salmon release groups among six different Delta junctions and the relationship was statistically significant ($p<0.001$). The probability of fish departing from the main river channel and entering a distributary did not follow a one-to-one relationship [95 % confidence interval for slope (0.61–0.94)]; fish were less likely to enter distributary routes relative to total flow proportion (Fig. 4).

Predicted routing at junctions

A greater proportion of flow entered distributaries at the two most upstream junctions that were strongly influenced by river inflow (Old River and Georgiana Slough). The mean predicted proportion of juvenile salmonids that would have entered the interior Delta at these junctions across all flow and diversion levels over 24 h ranged from 0.30 to 0.44 at the Head of Old River junction, and from 0.25 to 0.36 at Georgiana Slough

Table 1 Estimates of juvenile Chinook salmon entrainment into distributary routes at seven junctions in the Sacramento-San Joaquin Delta[a]

Junction	Abbreviation	Source	Observed proportion
Delta Cross Channel	DCC	Perry 2010	0.387
Delta Cross Channel	DCC	Perry 2010	0.179
Delta Cross Channel	DCC	Perry 2010	0.329
Georgiana Slough (DCC closed)	GEO	Perry 2010	0.200
Georgiana Slough (DCC closed)	GEO	Perry 2010	0.150
Georgiana Slough (DCC closed)	GEO	Perry 2010	0.313
Georgiana Slough (DCC open)	GEO	Perry 2010	0.161
Georgiana Slough (DCC open)	GEO	Perry 2010	0.230
Georgiana Slough (DCC open)	GEO	Perry 2010	0.388
Georgiana Slough (DCC open)	GEO	Perry 2010	0.183
Head of Old River	HOR	Buchanan et al. 2013	0.360
Head of Old River	HOR	Buchanan et al. 2013	0.520
Head of Old River	HOR	Buchanan et al. 2013	0.480
Head of Old River	HOR	Buchanan et al. 2013	0.440
Head of Old River	HOR	Buchanan et al. 2013	0.390
Head of Old River	HOR	Buchanan et al. 2013	0.520
Head of Old River	HOR	Buchanan et al. 2013	0.450
Head of Old River	HOR	Buchanan et al. 2013	0.430
Head of Old River	HOR	Buchanan et al. 2013	0.590
Head of Old River	HOR	SJRG 2013	0.410
Head of Old River	HOR	SJRG 2013	0.430
Head of Old River	HOR	SJRG 2013	0.370
Head of Old River	HOR	SJRG 2013	0.450
Sutter Slough	SUS	Perry 2010	0.230
Sutter Slough	SUS	Perry 2010	0.086
Sutter Slough	SUS	Perry 2010	0.217
Sutter Slough	SUS	Perry 2010	0.096
Steamboat Slough	STS	Perry 2010	0.115
Steamboat Slough	STS	Perry 2010	0.112
Steamboat Slough	STS	Perry 2010	0.104
Steamboat Slough	STS	Perry 2010	0.158
Turner Cut	TRN	SJRG 2011	0.090
Turner Cut	TRN	SJRG 2011	0.030
Turner Cut	TRN	SJRG 2011	0.000
Turner Cut	TRN	SJRG 2011	0.050
Turner Cut	TRN	SJRG 2011	0.150
Turner Cut	TRN	SJRG 2011	0.250
Turner Cut	TRN	SJRG 2011	0.070
Turner Cut	TRN	SJRG 2013	0.270
Turner Cut	TRN	SJRG 2013	0.190
Turner Cut	TRN	SJRG 2013	0.090

[a] All studies utilized acoustic tagging technology to estimate route entrainment. The Delta Cross Channel is a gate located just upstream of Georgiana Slough that when open, diverts water from the Sacramento River into the interior Delta

Table 2 Parameters used in DSM2 model runs to generate flow proportion estimates at nine junctions on the Sacramento and San Joaquin rivers

Treatment	Sacramento River inflow ($m^3 s^{-1}$)	San Joaquin River inflow ($m^3 s^{-1}$)	Total exports ($m^3 s^{-1}$)
Low inflow - low exports	317.9	42.2	60
Low inflow - medium exports	317.9	42.2	180
Low inflow - high exports	317.9	42.2	300
Medium inflow - low exports	547.9	82.1	60
Medium inflow - medium exports	547.9	82.1	180
Medium inflow - high exports	547.9	82.1	300
High inflow - low exports	968.6	171.4	60
High inflow - medium exports	968.6	171.4	180
High inflow - high exports	968.6	171.4	300

(Figs. 5, 6 and 7). Confidence intervals for these mean values were relatively small because the proportion of flow entering the interior delta at these junctions was close to the mean value from the linear regression. The predicted proportion of salmonids entering distributaries at the seven tidally dominated junctions did not exceed 0.16 at any level of inflow or diversions (Figs. 5, 6 and 7). The confidence intervals at these junctions were wide because proportional flow values were near the low end of the linear model.

Diversions had little effect on predicted fish routing into the interior Delta at Georgiana Slough (0.4–1 %; Figs. 5, 6 and 7) whereas at Head of Old River, diversions increased predicted fish routing into the interior Delta by as much a 7 % when inflow was low (Fig. 5). At the tidally dominated junctions, the maximum change produced by diversions was a 2 % increase in predicted routing into the interior Delta at Middle River when inflow was high (Fig. 7).

Changes in inflow had little effect on the predicted routing of salmonids into distributary channels at the tidally dominated junctions, with changes<1 % across all inflow and diversion levels. However, at the two riverine-dominated junctions (GEO and HOR), predicted routing into the interior Delta changed by up to 11 % across the three levels of river inflow. At HOR, a greater proportion of juvenile salmon were predicted to enter the interior Delta as flows increased whereas at Georgiana Slough, greater proportions of fish were predicted to enter the interior Delta as inflow decreased (Figs. 5, 6 and 7).

Table 3 Results of the model selection exercise comparing the ability of three hydrodynamic metrics to predict observed routing of juvenile Chinook salmon at seven Delta junctions

Predictor	AIC_c	ΔAIC_c	AIC_c weight
Proportion of flow into the distributary.	−77.6	0.0	1.0
Ratio of velocity in main channel to velocity in the distributary.	−29.4	48.2	0.0
Proportion of time that flow is entering the distributary.	−55.2	22.3	0.0

Discussion

The proportion of flow entering a distributary channel was selected as the best metric to explain route selection of juvenile Chinook salmon at junctions in the Delta. The linear model explained a significant fraction of the total variation in observed routing; however, fish were less likely to enter distributary routes relative to total flow proportion. These results suggest that total flow proportion at each junction can be used in conjunction with the linear model to predict fish routing. This will be an effective tool for evaluating water management actions on fish routing; especially where little or no observed fish routing data are available. For example, if managers propose to keep more fish in the main stem by increasing inflows or reducing diversion, they can use the model to determine how much flow proportions would need to be altered to achieve a measurable effect on observed routing.

The spatial location of junctions within the watershed appeared to have a large effect on hydrology and predicted routing. The two most upstream junctions were primarily influenced by river inflow and a greater

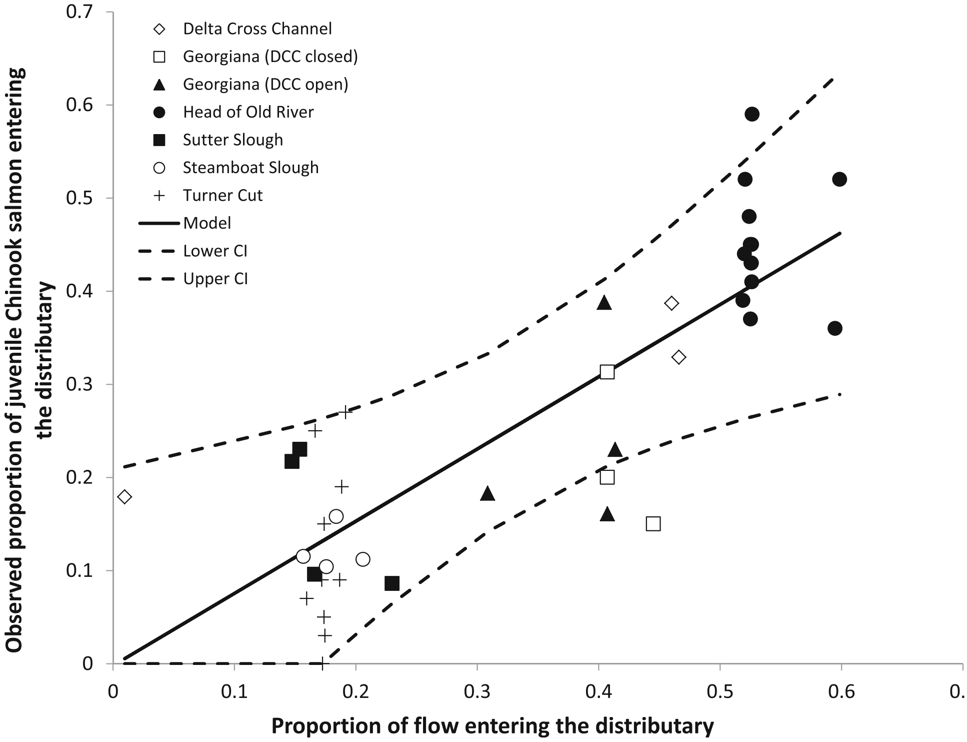

Fig. 4 Plot of observed routing at seven Delta junctions as a function of the proportion of total flow entering the distributary route. The solid line is the best-fit linear model as indicated by ΔAICc values. The dashed line is the 95 % confidence interval

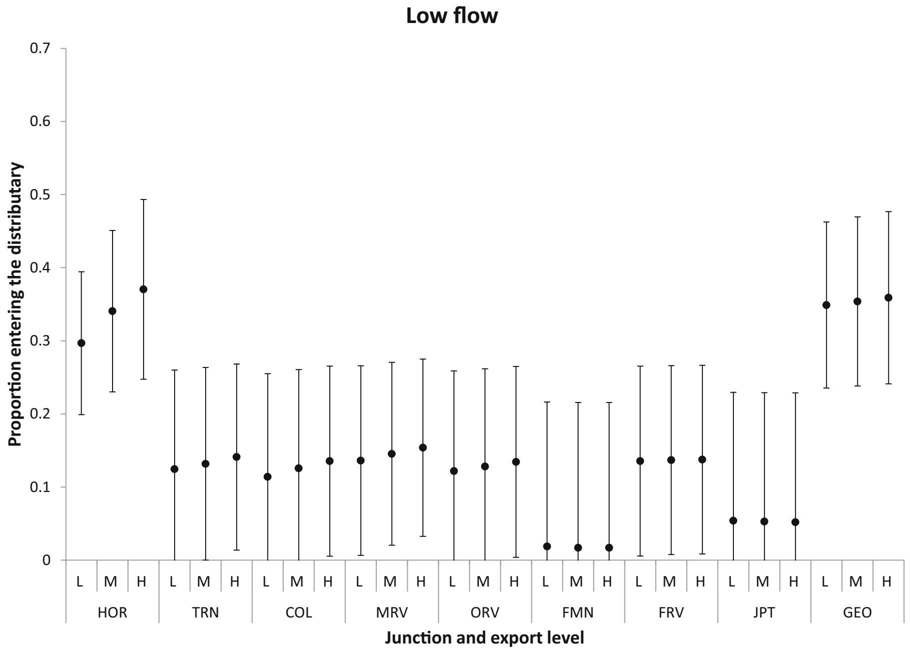

Fig. 5 Means with 95 % confidence intervals for predicted routing at nine Delta junctions under three levels of exports (60-, 180- and 300 $m^3 s^{-1}$) and low river inflow (Sacramento River= 317.9-, San Joaquin River=42.2 $m^3 s^{-1}$). Abbreviations: HOR = Head of Old River, TRN = Turner Cut, COL = Columbia Cut, MRV = Middle River, ORV = Old River, FMN = Fisherman's Cut, FRV = False River, JPT = Jersey Point, GEO = Georgiana Slough

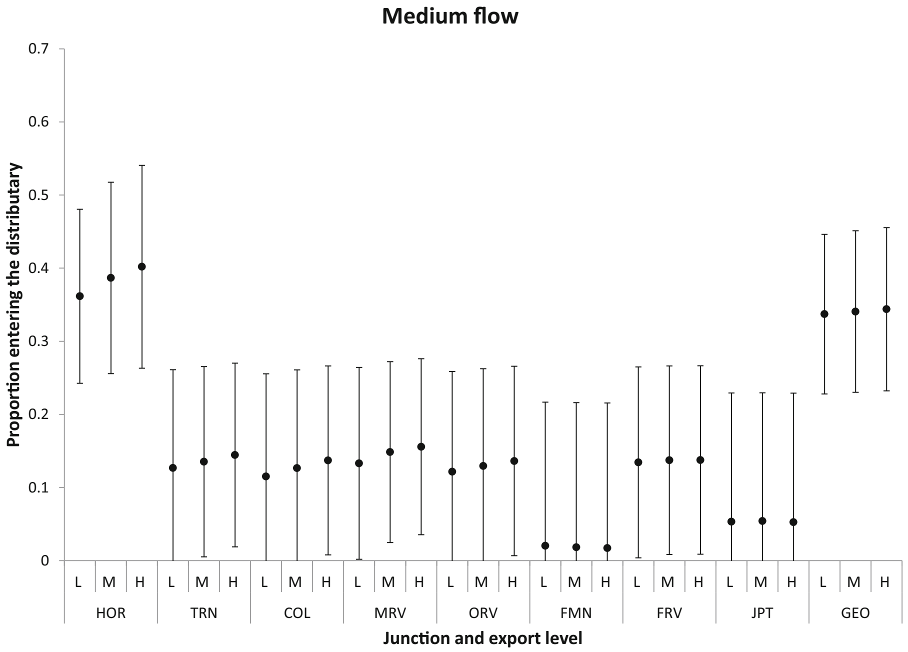

Fig. 6 Means with 95 % confidence intervals for predicted routing at nine Delta junctions under three levels of exports (60-, 180- and 300 $m^3 s^{-1}$) and medium river inflow (Sacramento River = 547.9-, San Joaquin River = 82.1 $m^3 s^{-1}$). Abbreviations: HOR = Head of Old River, TRN = Turner Cut, COL = Columbia Cut, MRV = Middle River, ORV = Old River, FMN = Fisherman's Cut, FRV = False River, JPT = Jersey Point, GEO = Georgiana Slough

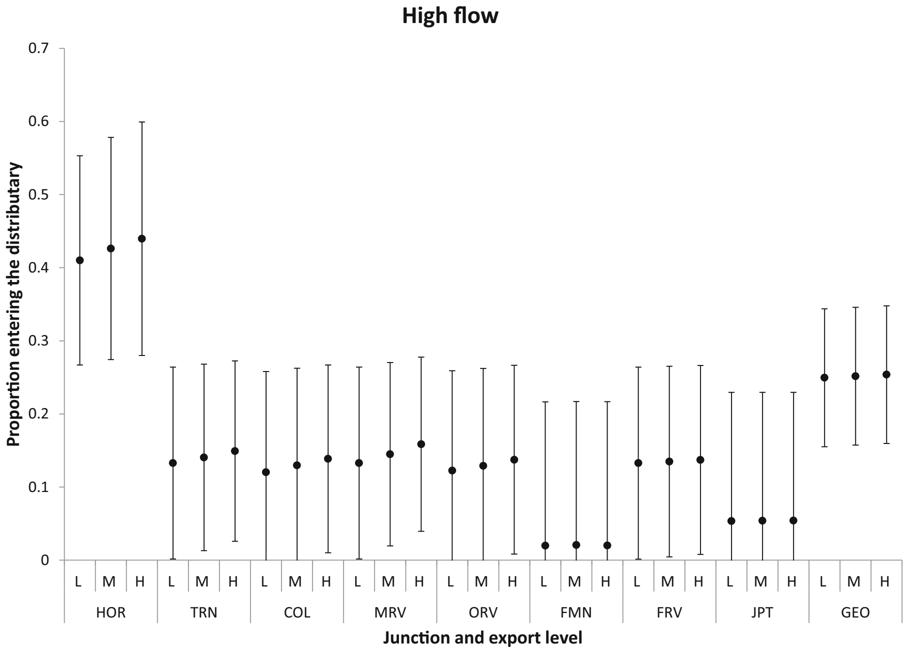

Fig. 7 Means with 95 % confidence intervals for predicted routing at nine Delta junctions under three levels of exports (60-, 180- and 300 $m^3 s^{-1}$) and high river inflow (Sacramento River= 968.6-, San Joaquin River=171.4 $m^3 s^{-1}$). Abbreviations: HOR = Head of Old River, TRN = Turner Cut, COL = Columbia Cut, MRV = Middle River, ORV = Old River, FMN = Fisherman's Cut, FRV = False River, JPT = Jersey Point, GEO = Georgiana Slough

proportion of salmon were predicted to enter the distributary route at these junctions relative to any of the seven tidally dominated junctions. Flow rarely changed direction with the tides at these junctions and some proportion of flow entered the distributary throughout the 24 h period except at the lowest inflow level. Total proportional flow into the distributary route responded differently to increasing levels of inflow at each of the riverine-dominated junctions. Flow into the distributary increased with inflow at one junction (HOR) and decreased at the other (GEO). This suggests that the morphology of junction channels may have a significant effect on the specific pattern of proportional flow (and predicted fish entry) into different routes as inflows increase. Diversions had a greater effect on predicted routing at the Head of Old River junction, likely because water is diverted from the Old River channel, but this effect attenuated at higher inflows. Only small diversion effects on predicted routing were detected at Georgiana Slough (GEO) across all flow levels and the distance of this junction from the diversion facilities likely influenced this result.

At the seven tidally dominated junctions, both inflows and diversions had relatively small effects on the predicted routing of fish into the interior Delta. The volume of water moving at these junctions as a result of tidal action is large compared to the volume influenced by river inflow and diversions (Baker and Morhardt 2001). The proportion of time that flow was into the distributary ranged from 49 to 60 %, which would be expected at junctions dominated by tidal influence where flow changes direction during each 24 h period. Channel morphology and spatial location appeared to have large effects on hydrodynamics at the tidally dominated junctions. At two junctions, total flow into the interior Delta was never greater than 7 % whereas total flow at other tidally dominated junctions ranged up to 21 %. The proportion of time that flow was toward the interior Delta was greater at the Old River junction (ORV) relative to other tidally dominated junctions because there is a direct connection to the diversion facilities on the Old River channel.

Previous studies of salmonid route selection suggest that proportional flow is a strong predictor of route selection (Kemp et al. 2005; Perry 2010). However, the use of total daily proportions as a variable in a linear model to estimate the percent of fish using that route should be undertaken with caution. The proportion of flow entering the distributary route varied greatly within a 24 h period for most junctions, but especially at the tidally dominated junctions. Thus, the point in the tidal cycle when a salmon arrives at a junction will have a large influence on the probability of entering a certain route. Indeed, Perry (2010) found that fish entrainment at Georgiana Slough closely followed changes in flow proportion with changing tides. Additionally, salmon may only actively migrate at night or only on ebb tides—further restricting the range of potential route use probabilities (Michel et al. 2013).

There may be potential to change inflow in order to manipulate route use probabilities at riverine-dominated junctions; however, manipulation of diversions is likely to only be useful at junctions with direct connections to the Old River channel where the diversion facilities are located; even then only at lowest levels of river inflow. At most of the nine junctions where routing was predicted using the linear model, flow proportions into the distributary were so low that the confidence intervals overlapped over the range of diversions and inflows examined. The values of diversions and inflows used here were selected because they represent a range of values under management control. Thus, it is unlikely that flow or diversion management actions would produce a detectable effect on routing at most junctions; especially in areas dominated by tidal flow. There was no evidence of a significant "pulling" of fish off of the main stem routes at the range of diversions examined, likely because the magnitude of tidal flow swamps out most of the diversion (and inflow) signal. Fish will enter distributary routes regardless of management of inflows and diversions. Preventing migrating salmonids from entering unfavorable distributary routes in the Delta may require the use of physical or non-physical barriers rather than hydrodynamic manipulation to produce detectable effects.

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