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# Effect of the Emergency Drought Barrier on the Distribution, Biomass, and Grazing Rate of the Bivalves *Corbicula fluminea* and *Potamocorbula amurensis*, False River, California

Open-File Report 2021–1088

U.S. Department of the Interior
U.S. Geological Survey

**Cover.** Sunrise at flooded island in Franks Tract State Recreation Area, Sacramento–San Joaquin River Delta, California. Photograph by Francis Parchaso, U.S. Geological Survey, May 16, 2003.

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# Contents



## Figures

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# Conversion Factors

International System of Units to U.S. customary units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| millimeter (mm) | 0.03937 | inch (in.) |
| | Area | |
| square meter ($m^2$) | 0.0002471 | acre |
| | Volume | |
| milliliter (mL) | 0.03381402 | ounce, fluid (fl. oz) |
| cubic meter ($m^3$) | 264.2 | gallon (gal) |
| | Flow rate | |
| liter per day (L/d) | 0.264172 | gallon per day (gal/d) |
| | Mass | |
| milligram (mg) | 0.00003527 | ounce, avoirdupois (oz) |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

## Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

## Abbreviations

| | |
|---|---|
| AFDW | ash-free-dry-weight |
| DWR | California Department of Water Resources |
| GRTS | Generalized Random Tessellation Stratified design study |
| $n_{max}$ | refiltration proportion |
| PR | species pumping rate |
| $PR_{wt}$ | pumping rate, expressed as weight |
| SJR West | San Joaquin River West |
| SR South | Sacramento River South |
| $S_P$ | Practical Salinity |

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## Executive Summary

Benthic samples were collected from the Sacramento–San Joaquin Delta of northern California to examine the effect of the changing hydrologic flow on the bivalves *Potamocorbula* and *Corbicula* before, during, and after the False River Barrier (hereafter, barrier) was in operation (May–November 2015). *Potamocorbula* moved upstream in the Sacramento River as the salinity intruded. Given the lower electrical conductivity of the San Joaquin River, *Potamocorbula* did not move as far upriver as it did in the Sacramento River. *Potamocorbula* recruits settled in the Sacramento and False Rivers, whereas *Corbicula* recruits were mostly found in the San Joaquin River. When the grazing rates for the two bivalves were combined, new populations of *Potamocorbula* plus existing *Corbicula* likely reduced the net growth rate of the phytoplankton in and just upstream from the Sacramento and San Joaquin River confluence region when the barrier was in place. Prior to the barrier installation, a very dry period assumably aided the success of *Potamocorbula* in the confluence region; nonetheless, they also responded to the increasing salinity in the Sacramento River and their population spatially expanded. *Potamocorbula's* upriver incursion was stopped owing to the return of freshwater flow due to the removal of the barrier, but the adults of the species were still present at the upstream end of Decker Island in January 2016. *Corbicula* adults did not seem to respond to the increased salinity caused by the barrier and maintained their biomass at all locations compared to what was recorded before the barrier.

## Introduction

Declining phytoplankton and zooplankton biomass, and the resulting stress on the food web, have been suggested as one contributor to the decline of delta smelt (*Hypomesus transpacificus* McAllister) and other fish species in the San Francisco Bay and the Sacramento and San Joaquin River Delta (hereafter, the Delta) (Sommer and others, 2007) of northern California. Filter feeding by two exotic bivalves, *Corbicula fluminea* and *Potamocorbula amurensis*, has been shown to control phytoplankton growth rate in the San Francisco Bay and the Delta. Because *Corbicula* is a freshwater bivalve and *Potamocorbula* is an estuarine bivalve, both species are thought to be partially responsible for the reduction in food for pelagic species (Kimmerer and Thompson, 2014; Lopez and others, 2006; Lucas and others, 2002; Lucas and Thompson, 2012). Both bivalve species are considered opportunistic, are particularly good at invading recently disturbed environments and are likely to be food-limited in the San Francisco Bay and the Delta. *Corbicula* and *Potamocorbula* distributions overlap in space, near the estuarine turbidity maximum where the salinity is approximately 2 Practical Salinity ($S_P$), and thus the bivalves can jointly act to reduce the base of the food web in both upstream and downstream environments.

The two bivalve species are critically different. *Potamocorbula* has a pumping rate about four times that of *Corbicula* and, given a similar biomass, a *Potamocorbula* population will result in larger grazing and phytoplankton loss rates than a *Corbicula* population. *Potamocorbula* can consume copepod nauplii (Kimmerer and Lougee, 2015; Kimmerer and others, 1994) and thereby affect the success of not only phytoplankton but also of an important food item for the Delta Smelt and other fish. *Potamocorbula* also accumulates selenium in its tissues, which is toxic to fish and wildlife and passed up the food web to its predators (for example, sturgeon [*Acipenser Linnaeus*] and diving duck [*Aythya* spp.]; Stewart and others, 2004) upon consumption. Thus, *Potamocorbula's* presence in what could be selenium rich water—resulting from changing sources of freshwater flowing into the estuary—are concerning to natural resource managers. To limit predator exposure to selenium and loss of pelagic food, it is important to understand the factors that control the distribution of *Corbicula* and *Potamocorbula*.

# Hypotheses of Bivalve Response

The Emergency Drought Barrier was an experiment that examines the response of each bivalve species' response to changing salinity distributions within physical habitats that do not normally experience these salinities. The barrier was constructed in May 2015 and fully removed by November 2015. The main hypothesis is that the barrier would limit the penetration of salt into the central Delta; therefore, the saline water would be diverted into the San Joaquin and Sacramento Rivers allowing *Potamocorbula* to move further up both rivers. Additionally, it was hypothesized that Big Break and Sherman Lake would likely see an increase in salinity and therefore an influx of *Potamocorbula*. If the barrier resulted in an increase in the residence time of water in Franks Tract and the surrounding areas, it was speculated that increased phytoplankton production might increase growth rate in both species of bivalves.Our specific hypotheses were as follows:
With Barrier in Place:

- $H_0$ *Potamocorbula* will move up the Sacramento and San Joaquin Rivers to locations where the salinity is in the 1–2 $S_P$ range on the river bottoms. Biomass and grazing rate will increase as a function of each species' preferred salinity (*Potamocorbula* 2 or more $S_P$ and *Corbicula* 10 or less $S_P$).
- $H_0$ Both bivalve species will increase their growth rate with increased water column residence times and increased primary production. Grazing rates will increase as the bivalve biomass increases.

After Barrier Removal:

- $H_0$ Adult *Potamocorbula* will remain in locations that receive some water with salinities 1 or more $S_P$. *Corbicula* adults will maintain their position if the salinity is 10 or less $S_P$.
- $H_0$ *Corbicula* recruits will settle in areas with a salinity of 2 or less $S_P$, whereas *Potamocorbula* will settle in areas with a salinity of 2 or more $S_P$.

# Study Rationale

This study uses the California Department of Water Resources (DWR) sampling design and their historical data for context, and augments the current DWR sampling program. DWR collects benthic samples at 175 stations in May and October (Generalized Random Tessellation Stratified design study [GRTS]) of every year (2007–present). Approximately 50 of these stations are in the area likely to be impacted by the barrier. Separating the effects of the barrier from the effects of the drought on (1) the two bivalve species' distribution and (2) growth of the two bivalve species is possible because of the availability of historical GRTS samples collected in May and October 2007–2012 and 2014–2015. The GRTS samples have been analyzed by the U.S. Geological Survey for biomass, grazing rate, mean size, and recruitment rate for both *Potamocorbula* and *Corbicula* (Zierdt Smith and others, 2021). These data allow comparison of this study's results with findings during previous dry, wet, and normal water years.

## Field Sampling

A subset of the GRTS stations from 2015 was sampled (fig. 1) during each month while the barrier was in place and for two months after it was breached. The selection of stations was based on areas where the bivalves were likely to change distribution or biomass because of the changing salinity, phytoplankton biomass, or phytoplankton composition. Stations were located in the Sacramento River, San Joaquin River, and the region of their confluence. Sites were sampled in August, September, November 2015, and January 2016 (GRTS samples were used to augment sampling in May and October). A 0.05-$m^2$ Ponar/van Veen grab was used to take one grab/location. Samples were screened through a 0.5-mm screen, preserved in 10-percent formalin, and stored in 70-percent ethyl alcohol.

## Laboratory Analyses

Samples were sorted to remove organisms from the sediment and bivalves were counted and identified. Other taxa were identified to family level if possible and archived. Bivalves were measured to the nearest mm using a video image analyzer with HL++ image software (Western Vision Software, 2010) for the smaller animals and using calipers for the larger animals. Biomass estimates (shown as ash-free-dry-weight [AFDW, weight of dried bivalve tissue without shell]) were based on relationships between length and dry tissue mass calculated by DWR during the May and October 2015 GRTS sampling, using the standard techniques described in Thompson and others (2008). Change in bivalve biomass and median size of bivalve were used to assess the growth rate of the bivalves. Bivalves whose length was equal to or less than 2.5 mm were considered recruits.

## Estimating grazing rates

Grazing rates (GR, $m^3/m^2$/day) were calculated using the method described in Thompson and others (2008) for *Potamocorbula* and in Lopez and others (2006) for *Corbicula*. Pumping rates were adjusted for temperature and were estimated as conservative rates (using a correction for concentration boundary layer). Species pumping rates (PR, L/day) were based on published relationships (Cole and others, 1992).

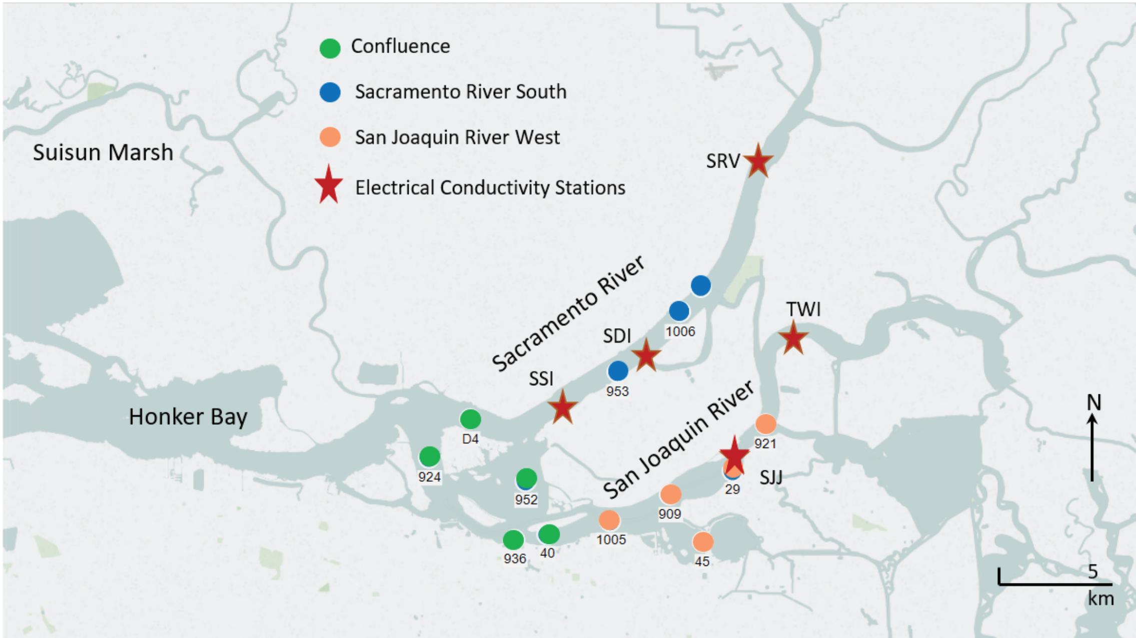


**Figure 1.** Station locations for benthic samples and California Data Exchange Center electrical conductivity stations, Sacramento–San Joaquin River Delta, California. Labels on round dots are station numbers and locations supplied by the California Department of Water Resources (DWR) for the Generalized Random Tessellation Stratified design study, which were sampled in this study. Colors of round dots designate the three regions that are shown in this report: the Confluence, the Sacramento River South, and the San Joaquin River West. Letter labels on red stars represent California Data Exchange Center stations (DWR, 2020) that were used for the electrical conductivity data in figures 2–6.

$$\textit{Potamcorbula}\ \mathrm{PR} = \mathrm{AFDW}\ ((400\mathrm{L}(gAFDW)-1)(day)-1) \quad (1)$$

where

$$\mathrm{AFDW} = \text{dry weight (g)–ash weight (g)}$$

Pumping rates were converted to grazing rates by reducing the PR to adjust for the presence of a concentration boundary layer. This adjustment is based on the O’Riordan and others (1995; figure 7b) refiltration relationship, where $n_{\max}$ is the maximum refiltration proportion. In the following equation, the refiltration proportion ($n_{max}$) is that proportion of water previously filtered by 1 m$^2$ of bivalves.

$$(\mathrm{GR} = \mathrm{PR}\ (1 - n_{max})) \quad (2)$$

where

$n_{max} = \mathrm{r}(s(d\ o)-1)-1$, and

$r = 2$ for *Potamocorbula* and r = 3 for *Corbicula*.

The distance between siphon pairs, $s$, is a measure of animal density, and $d_o$ is the average diameter of the excurrent siphon of the animals collected at each site (a measure of bivalve size). The diameter of the excurrent siphon was changed throughout the study to reflect the change in average size of bivalves as the study progressed, and the distance between siphon pairs was based on the density of animals noted in our benthic sampling, assuming equidistant spacing within the 0.05-m$^2$ grab. Benthic grazing rates calculated in this manner represent the minimum grazing rates, as they assume that the near bottom boundary layer is depleted of phytoplankton and mixing of the water column is inadequate to replenish that lower layer with phytoplankton biomass. All bivalves were assumed to graze continuously.

*Corbicula* dry weight was used to estimate their temperature corrected pumping rates. Pumping rate expressed as a unit of weight ($PR_{wt}$) was derived from data published by Foe and Knight (1986) for *Corbicula* from the Delta:

$$PR_{wt}(ml(mgAFDW)-1\,hour-1) = 0.4307\,e\ 0.1113(temperature) \quad (3)$$

determined valid for temperatures from 16 to 30 °C. Pumping rate for each individual bivalve was calculated as $PR\ (L/d) = (PR_{wt})(AFDW)$.

Calculated pumping rates were converted to grazing rates assuming a maximum effect of a concentration boundary layer by decreasing pumping rate using the refiltration relationship shown in equation 2.

## Data Analyses

Geographic descriptors were used to group GRTS stations; these descriptors and the number of stations assigned to each geographic descriptor are shown in table 1.1. Median biomass, grazing rate, size of animal in a sample, and average recruit abundance for the barrier station samples were compared with data collected for the same geographic region in May and October 2007–15 (Shrader and others, 2020; Zierdt Smith and others, 2021). We compared all 2015 data with each of the prior GRTS datasets to help delineate drought and barrier effects (table 1.1).

# Results

## Hydrologic Years

The distribution of these two species of bivalves is limited by salinity as each species has a physiologic limit on the amount of salt they need (*Potamocorbula*) or can withstand (*Corbicula*). The best indicator of each species' distribution and success is therefore the salinity or electrical conductivity of the water. The primary controls on salinity in this system are the relatively constant salinity tidal waters and the varying anthropogenically controlled freshwater flow from the rivers and tributaries. The designation of hydrologic year index by the DWR is a measure of the freshwater variability and availability and is dependent on current and antecedent conditions. As shown in table 1.2, most of GRTS sampling have been done during dry or critically dry years.

## Electrical Conductivity Data

Electrical conductivity data from five California Data Exchange Center (DWR, 2020) stations that are within the area of study are shown (fig. 1). The known salinity limit for *Potamocorbula* and *Corbicula* is 2 or more $S_P$ and 2 or less $S_P$ respectively (approximately 3,800 µS/cm) and is shown for each location (figs. 2–6). At the northernmost station on the Sacramento River, at Rio Vista, there were only limited periods when the salinity was high enough to support *Potamocorbula*, and the longest period in this range was in December 2015. The next two downriver stations, SDI at Decker Island and SSI near Sherman Lake, consistently measured periods each day when the water salinity was favorable for each bivalve species until late December when the salinity dropped quickly. Two stations are shown (fig. 1) on the San Joaquin River. The first is a Jersey Point (SJJ), which is downriver of the barrier, recorded much salinity variability (although most months have periods that would favor each bivalve; fig. 5). The Twitchell Island station (TWI) is upriver of the barrier and recorded salinity that was consistently less than 2 $S_P$, except for a few days in November (fig. 6). The daily variability in salinity values at all stations was driven by tidal variability and changes in salinity were difficult to attribute to the barrier placement, until the barrier was removed. The high spikes in salinity in late November at Twitchell Island and Jersey Point might have been related to barrier removal in October, which allowed bay water to intrude further up the San Joaquin River. The connection between the salinity increase and the barrier removal is supported by similar spikes in salinity recorded at the down-bay station at Sherman Lake (fig. 4; SSI in fig. 1).

## Bivalve Biomass, Grazing Rate and Recruit Abundance Data

### Bivalves from Years Prior to the Barrier Placement

Bivalve biomass, grazing rate, and recruit distribution during the GRTS sampling period (2007–15) can provide valuable context for what was present prior to building the barrier and what was recorded in different hydrologic years. Figures 7 and 8 show the relative value for each species in the geographic areas most influenced by changes in water quality due to the barrier placement (confluence, San Joaquin River West [SJR West], and Sacramento River South [SR South]). Two areas (Honker Bay and Suisun Marsh) down-bay of the barrier zone host both bivalve species, providing valuable data for defining areas where the species overlap.

In general, *Corbicula* persistently dominates the biomass in the confluence, SJR West, and SR South regions and *Potamocorbula* does so in Suisun Marsh and Honker Bay, owing to the salinity distribution of the respective regions. The species overlap in the confluence during dry years (2008–09, 2012–15; see table 1.2 for hydrologic year designations) was due to the intrusion of *Potamocorbula* as the salinity moved upriver. *Potamocorbula* were present in the SR South region during 2014–15, and in lower numbers in the dry year 2009. *Potamocorbula* did not occur in SJR West until October 2015 with small biomass values (fig. 7).

Recruits from both species are well represented in the confluence. SR South showed a higher number of *Potamocorbula* recruits than SJR West in the dry years of 2009 and 2014–15 (fig. 7).

Grazing rate and grazing rate turnover (fig. 8) indicate the effect of the bivalves on the pelagic food sources because *Potamocorbula* has a higher pumping rate than *Corbicula*. The comparison of biomass and grazing rate plots for both species can differ in areas where the bivalves overlap. *Potamocorbula* grazing increased in importance in the confluence relative to *Corbicula* in 2014 and 2015 and therefore was already important in that region when the barrier was built. When the grazing of both bivalves is combined, it was estimated that the bivalves turned over the water column every 4–5 days in May 2015.

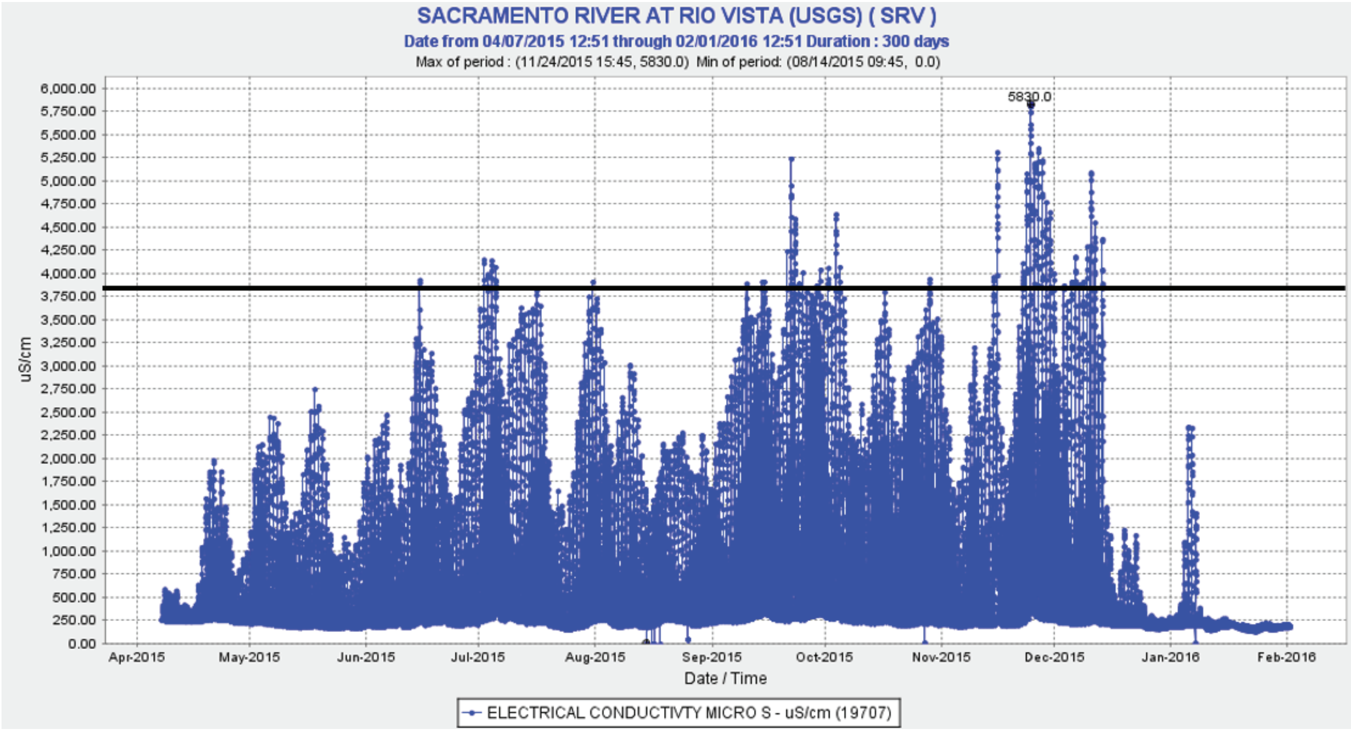


**Figure 2.** Electrical conductivity (microsiemens per centimeter [µS/cm]) of near surface water at Rio Vista on Sacramento River (SRV in fig. 1) in the Sacramento–San Joaquin River Delta, California, 2015–16. Black line shows electrical conductivity that approximates a salinity of about 2 Practical Salinity.

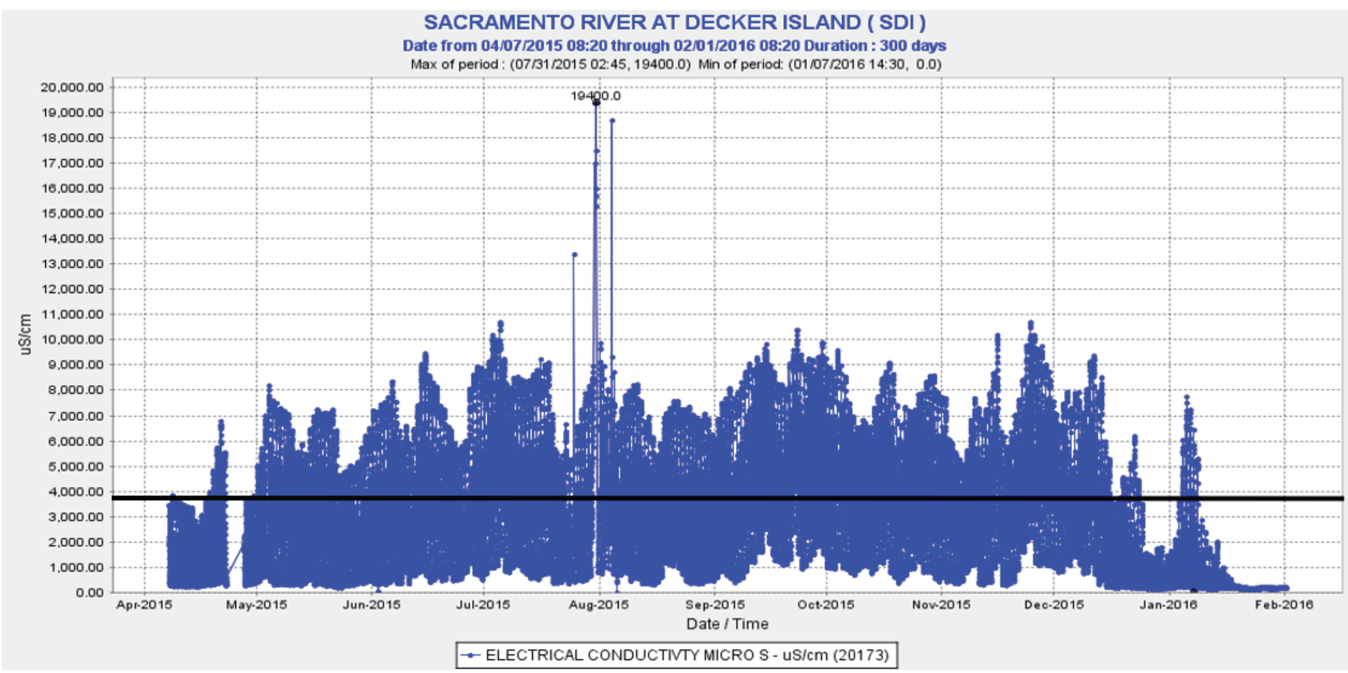


**Figure 3.** Electrical conductivity (microsiemens per centimeter [µS/cm]) of near surface water at Decker Island on Sacramento River (SDI in fig. 1) in the Sacramento–San Joaquin River Delta, California, 2015–16. Black line shows electrical conductivity that approximates a salinity of about 2 Practical Salinity.

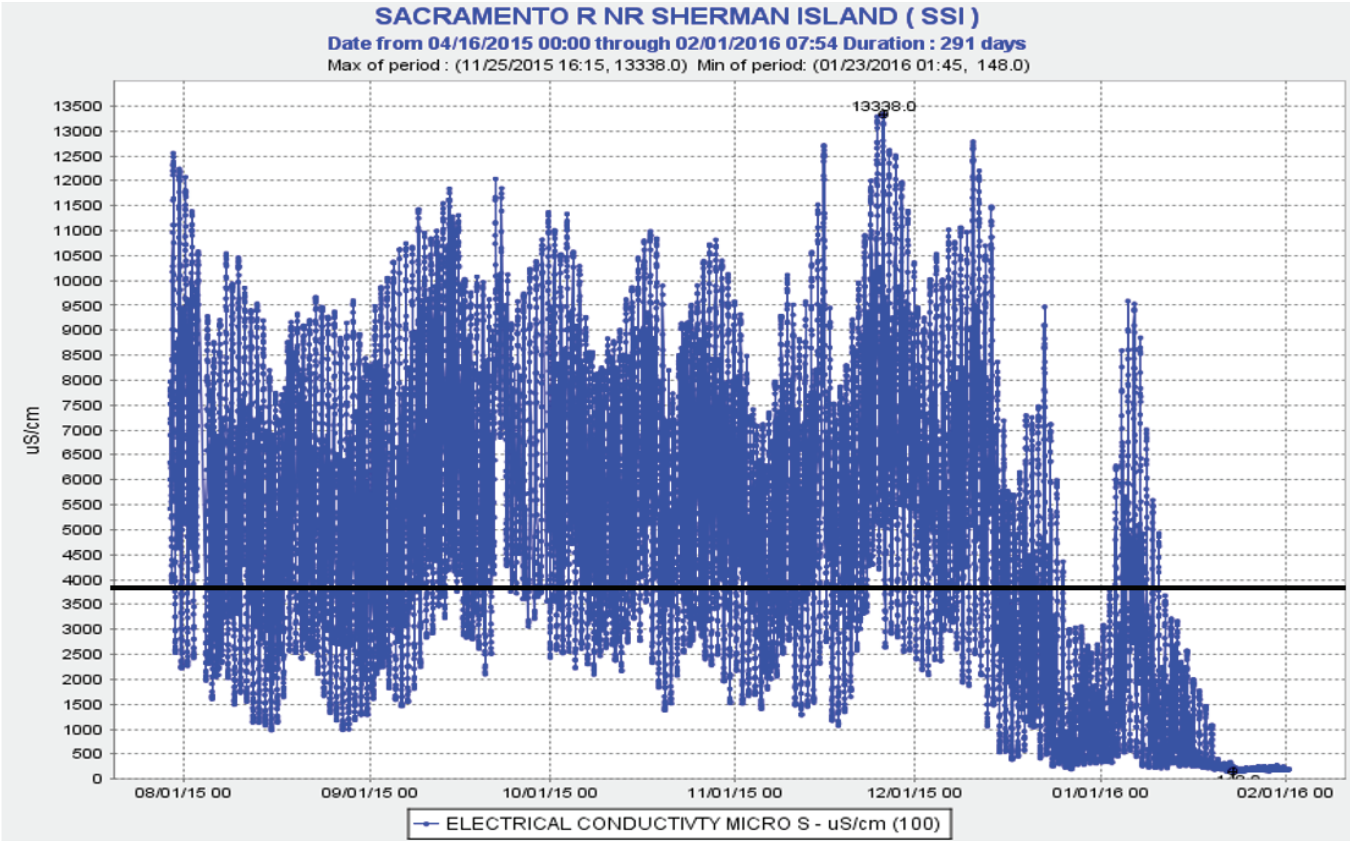


**Figure 4.** Electrical conductivity (microsiemens per centimeter [µS/cm]) of near surface water at Sherman Lake on Sacramento River (SSI in fig. 1) in the Sacramento–San Joaquin River Delta, California, 2015–16. Black line shows electrical conductivity that approximates a salinity of about 2 Practical Salinity.

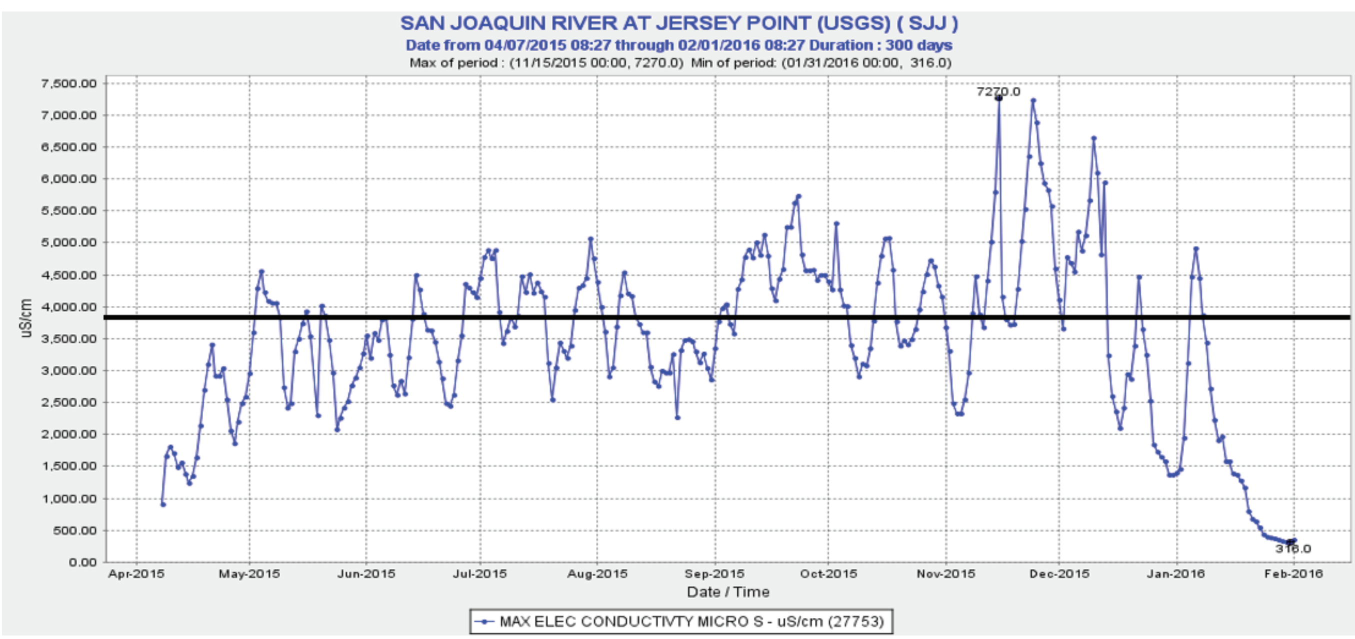


**Figure 5.** Electrical conductivity (microsiemens per centimeter [µS/cm]) of near surface water at Jersey Point on San Joaquin River (SJJ in fig. 1) in the Sacramento–San Joaquin River Delta, California, 2015–16. Black line shows electrical conductivity that approximates a salinity of about 2 Practical Salinity.

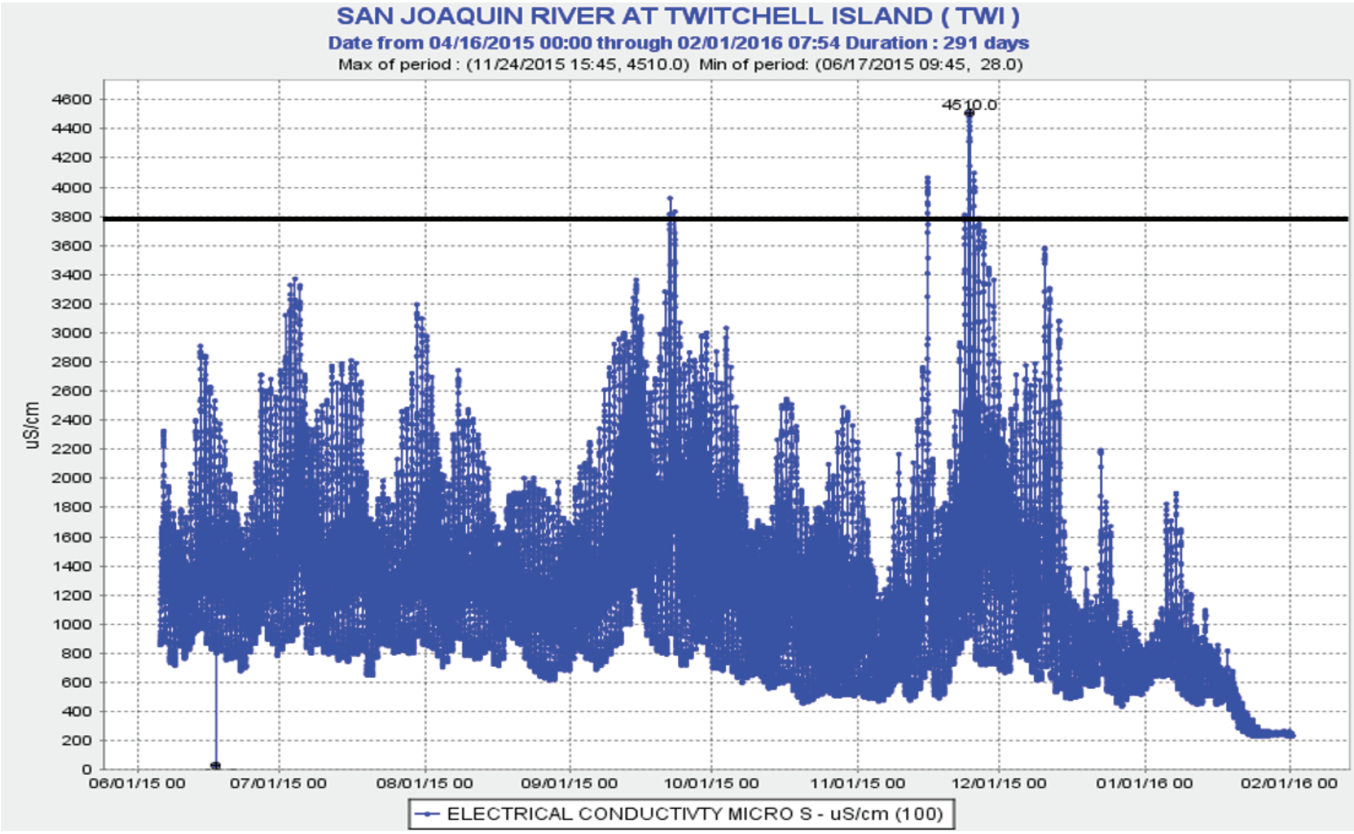


**Figure 6.** Electrical conductivity (microsiemens per centimeter [µS/cm]) of near surface water Twitchell Island on San Joaquin River (TWI in fig. 1) in the Sacramento–San Joaquin River Delta, California, 2015–16. Black line shows electrical conductivity that approximates a salinity of about 2 Practical Salinity.


**Figure 7.** *A*, Biomass (grams ash-free-dry-weight per square meter [g AFDW/m$^2$]) and *B*, recruit (bivalves whose length was equal to or less than 2.5 millimeters) abundance (number of recruits per 0.05 m$^2$) for *Potamocorbula* and *Corbicula* at barrier relevant stations based on the Generalized Random Tessellation Stratified design study shown in figure 1. Areas where *Potamocorbula* and *Corbicula* overlap result in a pie diagram representing both species with the total diameter representing the total biomass and total recruit abundance. Geographic areas are Honker Bay, Suisun Marsh, confluence, San Joaquin River Western area (SJR West), and Sacramento River southern area (SR South). May and October data shown in the Sacramento–San Joaquin River Delta, California, 2007–12 and 2014–15.

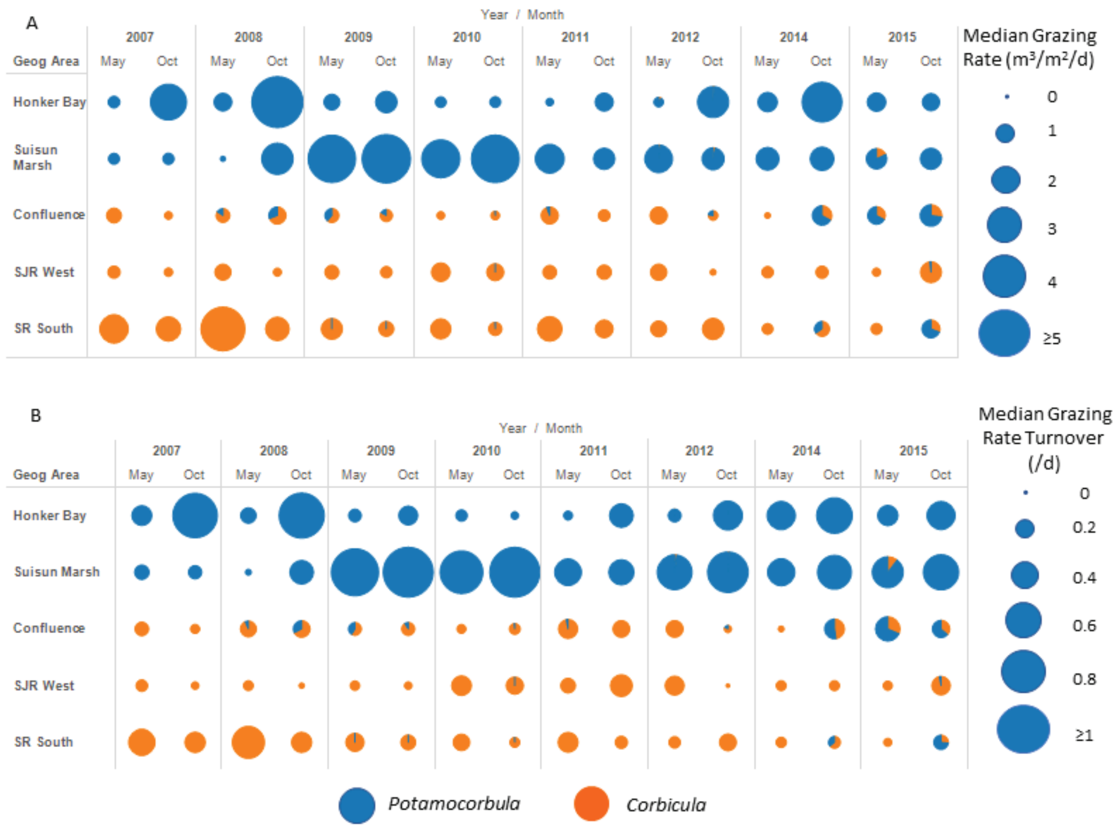


**Figure 8.** *A*, Grazing rate (cubic meter per square meter per day [$m^3/m^2/d$] or volume of water filtered/area/day) for *Potamocorbula* and *Corbicula* and *B*, grazing rate turnover (grazing rate normalized by depth resulting in units of number of times the water column was turned over) per day (/d) for *Potamocorbula* and *Corbicula* at barrier relevant stations from the Generalized Random Tessellation Stratified design program developed by the California Department of Water Resources. Areas where *Potamocorbula* and *Corbicula* overlap result in a pie diagram representing both species with the total diameter representing the total grazing rate and total grazing rate turnover. Geographic areas are Honker Bay, Suisun Marsh, confluence, San Joaquin River Western area (SJR West), and Sacramento River southern area (SR South). May and October data shown in the Sacramento–San Joaquin River Delta, California, 2007–12 and 2014–15.

The barrier was built during a very dry period in the Delta (May–November 2015) when the presence of immature and mature bivalves was most likely to overlap in the area of the confluence (both can live in a salinity of about 2 $S_P$). At the beginning of the barrier construction both species of bivalves were present in the SR South and confluence regions (fig. 7). *Potamocorbula* had some of the highest recruit abundance noted in the upper bay in May in Honker Bay and Suisun Marsh (fig. 7).

## Bivalve Distribution and Activity with Barrier in Place

The presence of the bivalves during the barrier study in the context of the prior years of sampling is shown (figs. 9–11). The biomass was not above normal during the barrier period except for one unusually large accumulation of *Corbicula* in the confluence in September 2015 that coincided with the lowest *Potamocorbula* biomass noted in that region. Higher *Potamocorbula* recruit abundance occurred in May 2015 than in other springs, and the abundance of *Potamocorbula* recruits in October 2015 was also unusually high. Previously, low *Potamocorbula* recruitment had been noted in the rivers, but the recruits were relatively abundant in SR South and present in SJR West from August through November 2015 (fig. 9).

Neither species showed a large growth spurt during the barrier study based on shell length (fig. 10). In general, *Corbicula* size is more stable over time than *Potamocorbula* size. Reductions in size were coincident with periods of high recruitment (fig. 9).

Grazing rate and grazing rate turnover values (fig. 11) indicate the importance of the presence of *Potamocorbula* in the confluence and SR South regions. In the confluence in particular, the combination of the high grazing turnover rates when values for both species are combined (table 1; August turnover time is approximately 4 days) shows that bivalves likely had an influence on primary producer growth rate. Over multiple years, *Corbicula* biomass and grazing rate declined as salinity increased during dry years, and the biomass of immigrating *Potamocorbula* compensated for the lost *Corbicula* biomass and grazing (fig. 8).

*Potamocorbula* recruit abundance was limited to the confluence at the start of the barrier placement in May (fig. 12), however the recruits moved up the San Joaquin and Sacramento Rivers by August 2015. The recruits did not intrude beyond Big Break on the San Joaquin River but continued to migrate beyond Decker Island on the Sacramento River by November. Thereafter, *Potamocorbula* recruits began declining and were present only in downriver locations in January.

*Corbicula* recruit occurrence was mostly limited to the San Joaquin River and one location at the northern end of Decker Island (fig. 13; SDI in fig. 1) on the Sacramento River. *Corbicula* recruit abundance was lowest in May and was relatively high through January 2016.

*Potamocorbula* biomass (fig. 14) followed the spatial pattern noted with recruits; *Potamocorbula* biomass was highest in the SR South and confluence regions and largely absent from the SJR West region. *Corbicula* did not follow the recruit distribution pattern; adult *Corbicula* were found in both the San Joaquin and Sacramento Rivers. As in previous plots, the grazing rate turnover time series (fig. 15) shows how important and dominant *Potamocorbula* is in filtering the water column and how important they were everywhere during the barrier period, except in the San Joaquin River.

A summary of the total bivalve biomass and grazing rate turnover time, and the number of days it could take the bivalves to turn over the water column (assuming a well-mixed water column), is listed in table 1. The values in this table are a good example of how species, water depth, and temperature, all influence pumping rate and must be considered when assessing the importance of bivalve grazing.

**Table 1.** Combined biomass (grams ash-free-dry-weight/square meter [g AFDW/m$^2$]), grazing rate turnover (number of times the water column was turned over) per day, and turnover time (days) for *Potamocorbula* and *Corbicula* during the period when the barrier was built (May 2015), the barrier was removed (November 2015), and after the barrier was removed (January 2016).

| Date | Biomass (g AFDW/m$^2$) | Grazing rate turnover (per day) | Turnover time (days) |
|---|---|---|---|
| May 5, 2015 | 2.2 | 0.07 | 14 |
| August 18, 2015 | 3.0 | 0.24 | 4 |
| September 9, 2015 | 3.1 | 0.08 | 12 |
| October 8, 2015 | 6.1 | 0.18 | 5 |
| November 4, 2015 | 5.3 | 0.12 | 8 |
| January 27, 2016 | 1.9 | 0.06 | 16 |

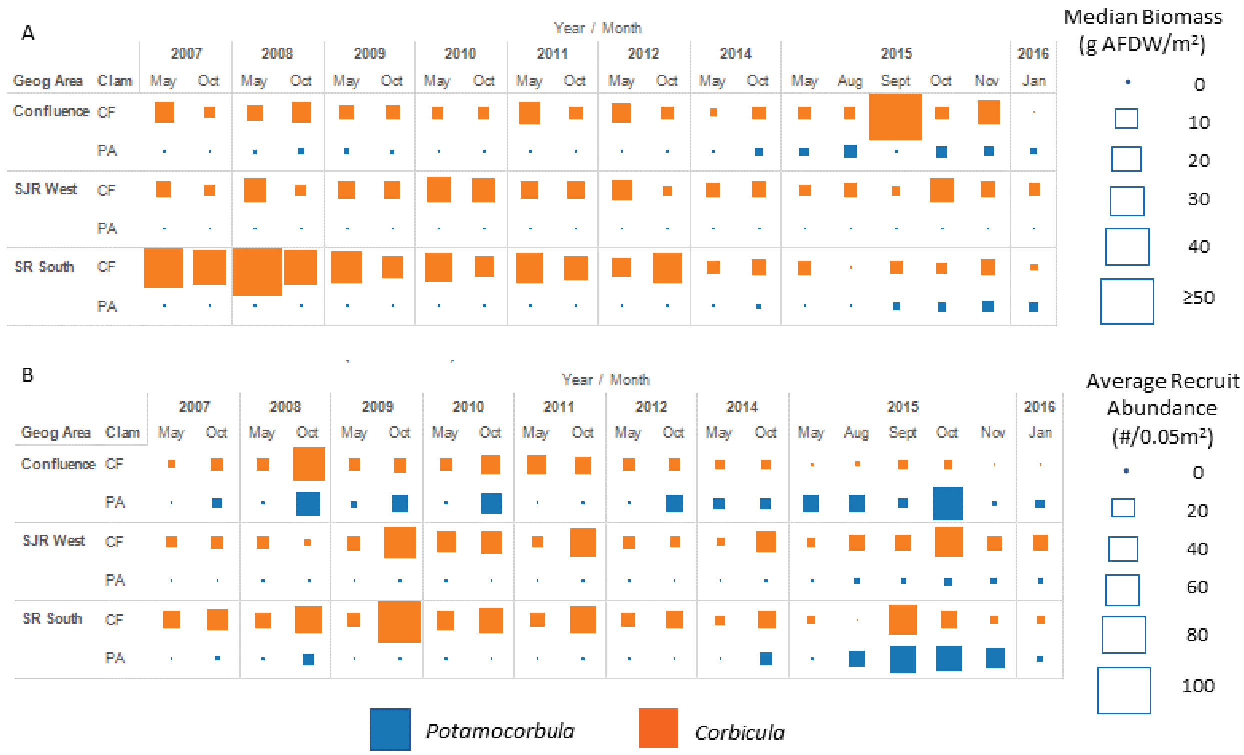


**Figure 9.** *A*, Biomass (grams ash-free-dry-weight per square meter [g AFDW/m$^2$]) and *B*, recruit (bivalves whose length was equal to or less than 2.5 millimeters) abundance (number of recruits per 0.05 m$^2$) for *Potamocorbula* and *Corbicula* at the three areas where both bivalves are most likely to concurrently occur (confluence, San Joaquin River Western area [SJR West], and Sacramento River southern area [SR South] as shown in fig. 1). Data are from the Sacramento–San Joaquin River Delta, California, 2007–12 and 2014–16.

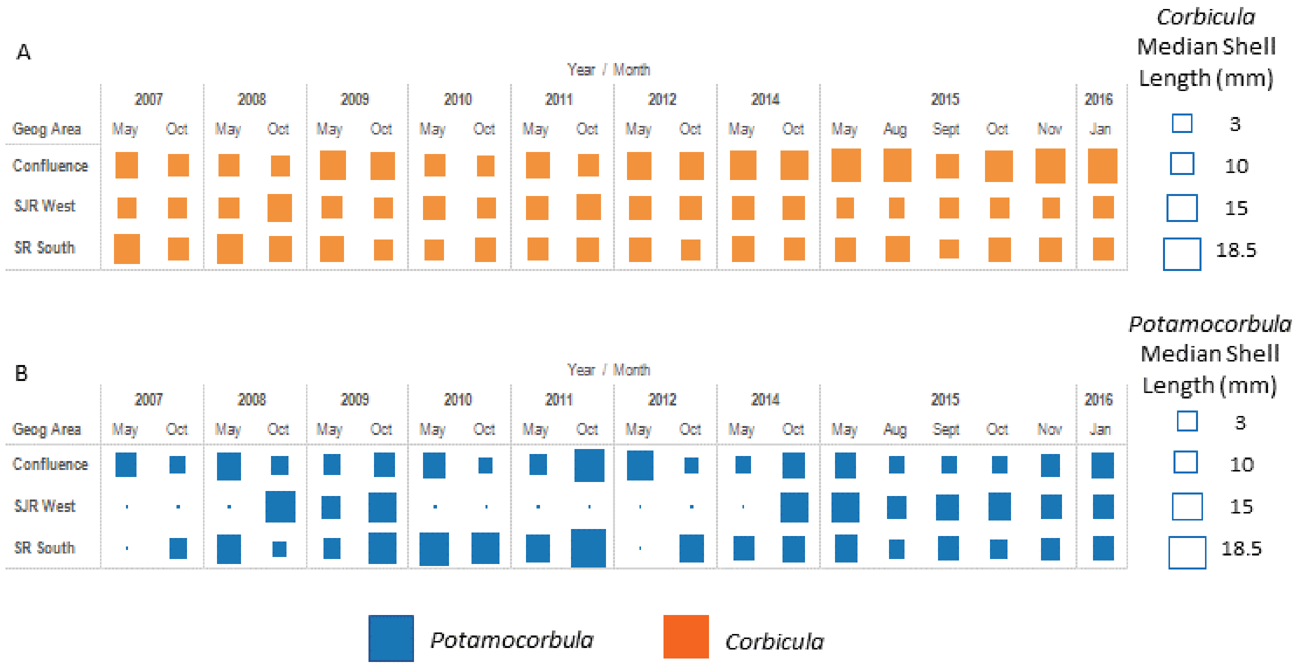


**Figure 10.** Median shell length (millimeters [mm]) of *A*, *Corbicula* and *B*, *Potamocorbula* at the three areas where both bivalves are most likely to concurrently occur (confluence, San Joaquin River Western area [SJR West], and Sacramento River southern area [SR South] as shown in fig. 1). Data are from the Sacramento–San Joaquin River Delta, California, 2007–12 and 2014–16.

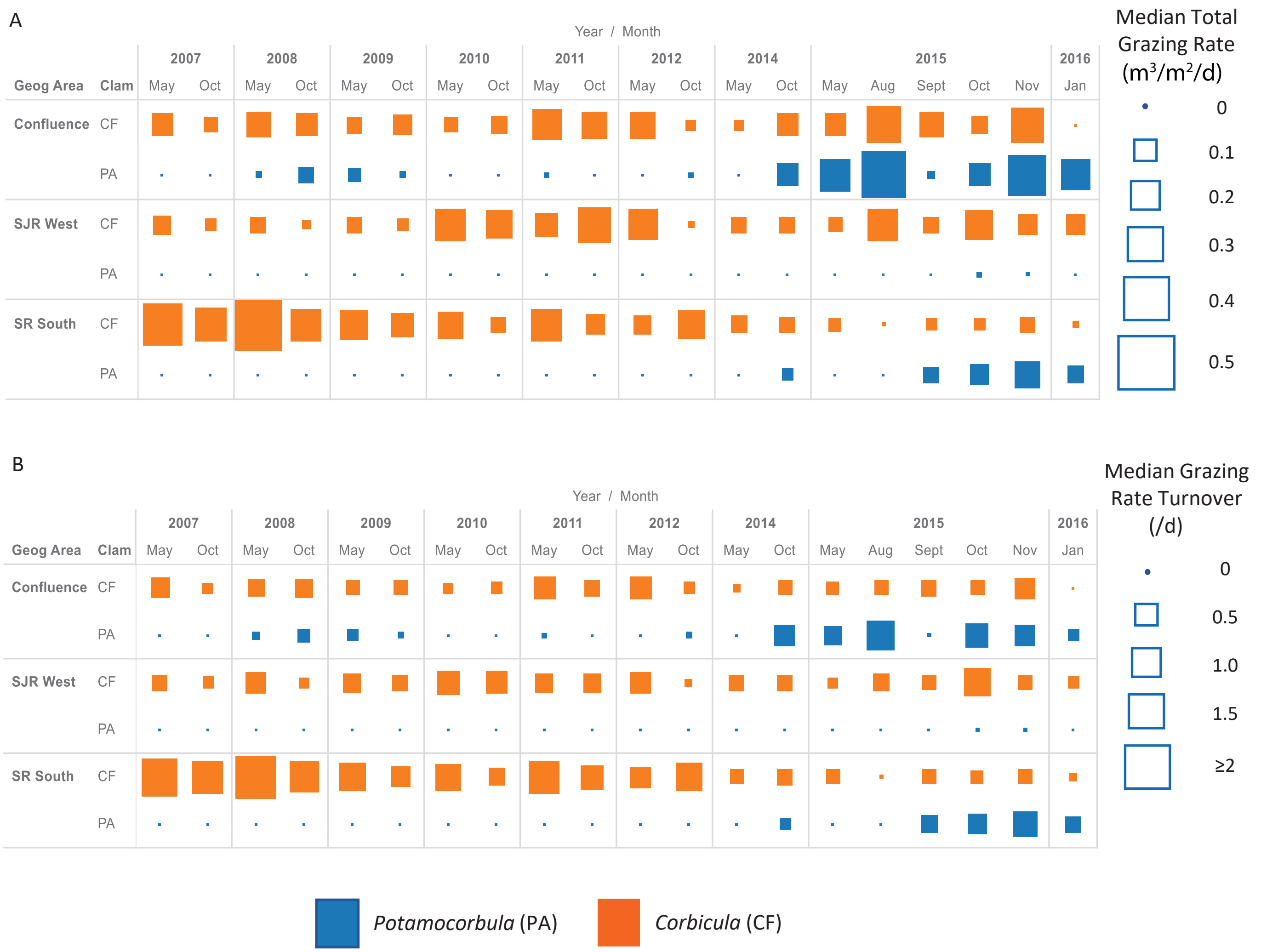


**Figure 11.** *A*, Median grazing rate (cubic meter per square meter per day [m³/m²/d] or volume of water filtered/area/day) and *B*, median grazing turnover rate (grazing rate normalized by depth resulting in units of number of times the water column was turned over) per day (/d) for *Potamocorbula* and *Corbicula* at the three areas where both bivalves are most likely to concurrently occur (confluence, San Joaquin River Western area [SJR West], and Sacramento River southern area [SR South] as shown in fig. 1). Data is from the Sacramento–San Joaquin River Delta, California, 2007–12 and 2014–16.

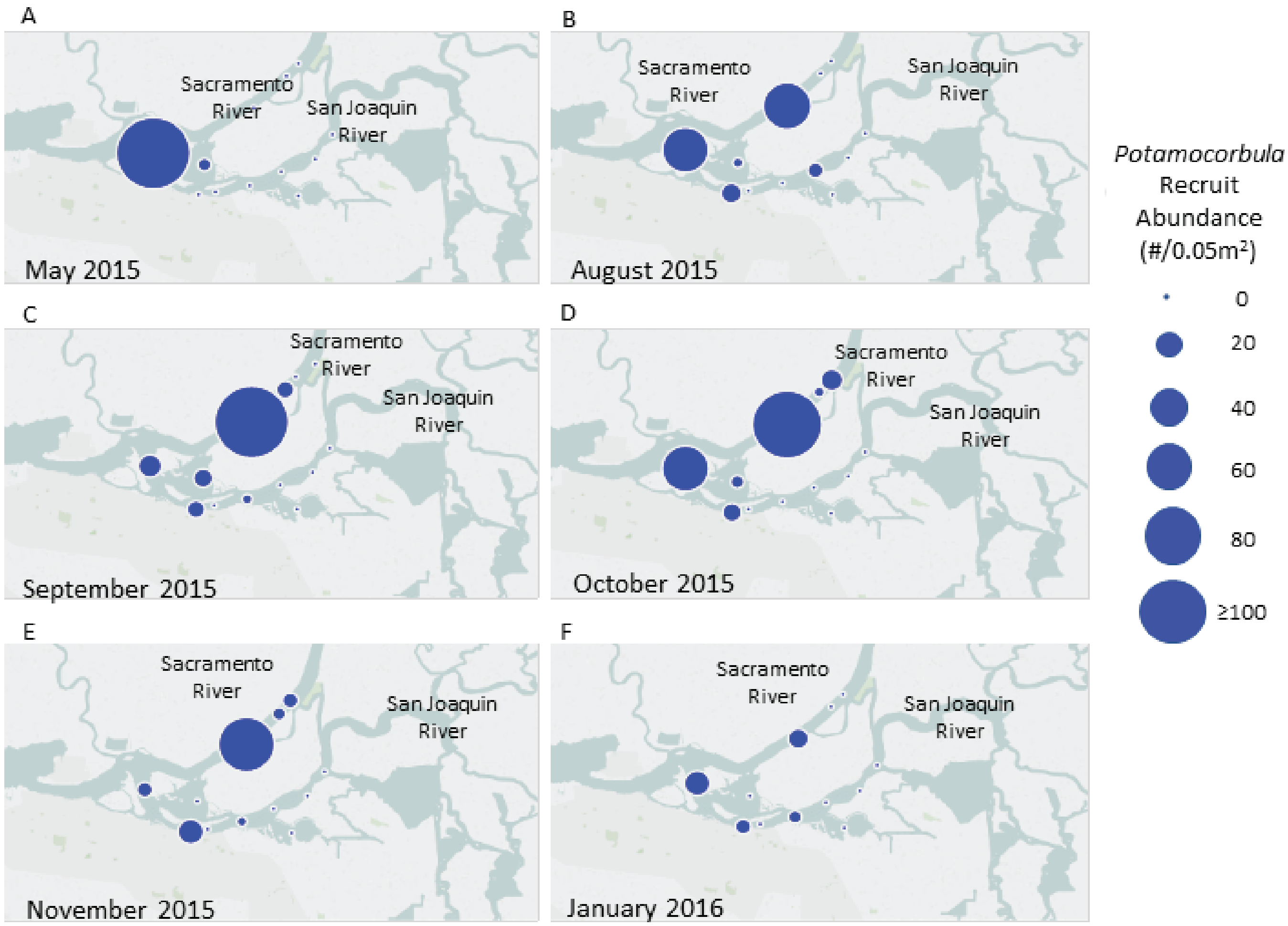


**Figure 12.** Recruit (bivalves whose length was equal to or less than 2.5 millimeters [mm]) abundance (number of recruits per 0.05 square meters [#/0.05 $m^2$]) for *Potamocorbula* at the three areas where bivalves were most likely to be influenced by change in salinity as a result of the barrier placement (confluence, San Joaquin River, and Sacramento River sampling stations shown in fig. 1). Data are from the Sacramento–San Joaquin River Delta, California, during the period immediately after the barrier placement and after its removal, May 2015–January 2016.

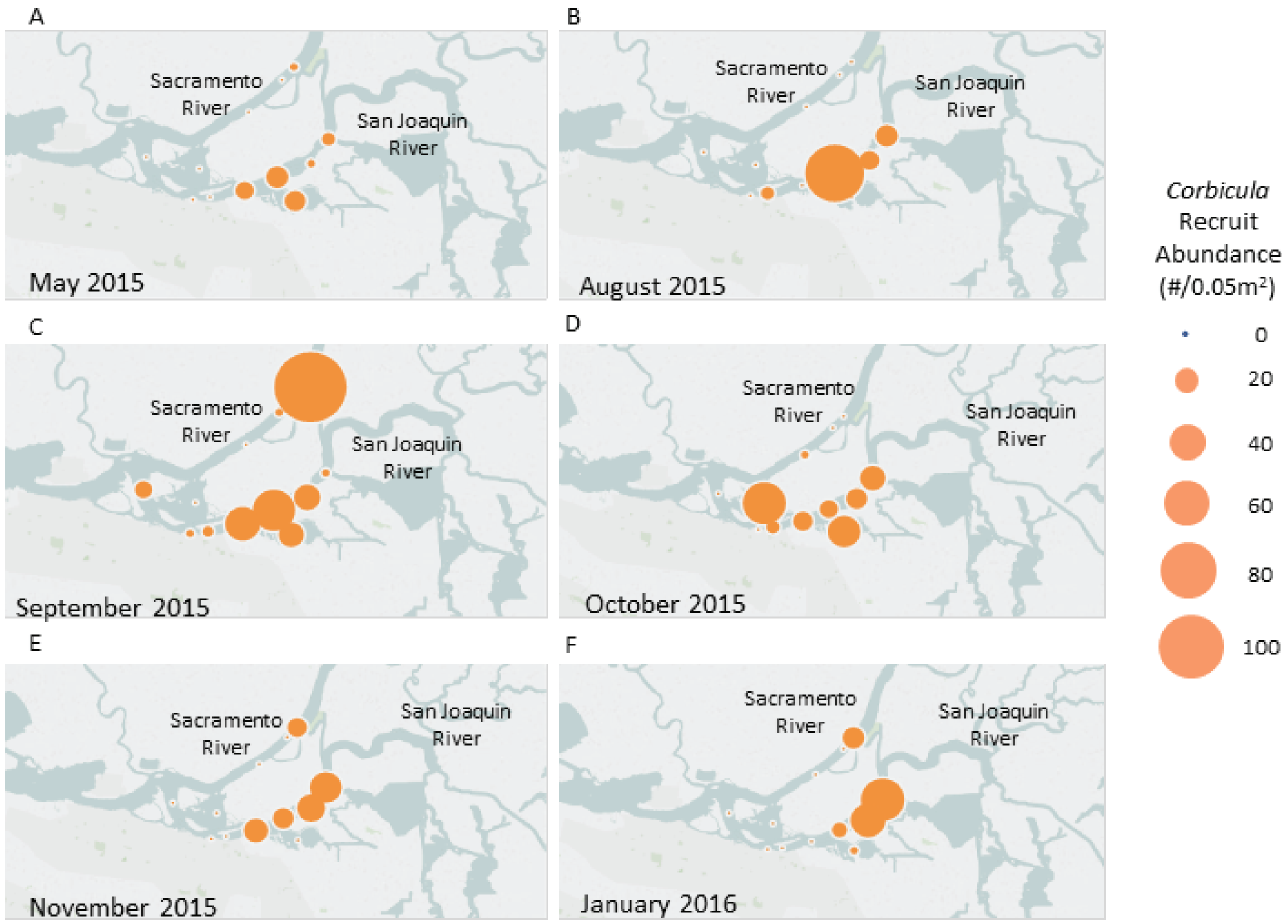


**Figure 13.** Recruit (bivalves whose length was equal to or less than 2.5 millimeters [mm]) abundance (number of recruits per 0.05 square meters [#/0.05 m²]) for *Corbicula* at the three areas where bivalves were most likely to be influenced by change in salinity as a result of the barrier placement (confluence, San Joaquin River, and Sacramento River sampling stations shown in fig. 1). Data are from the Sacramento–San Joaquin River Delta, California, during the period immediately after the barrier placement and after its removal, May 2015–January 2016.

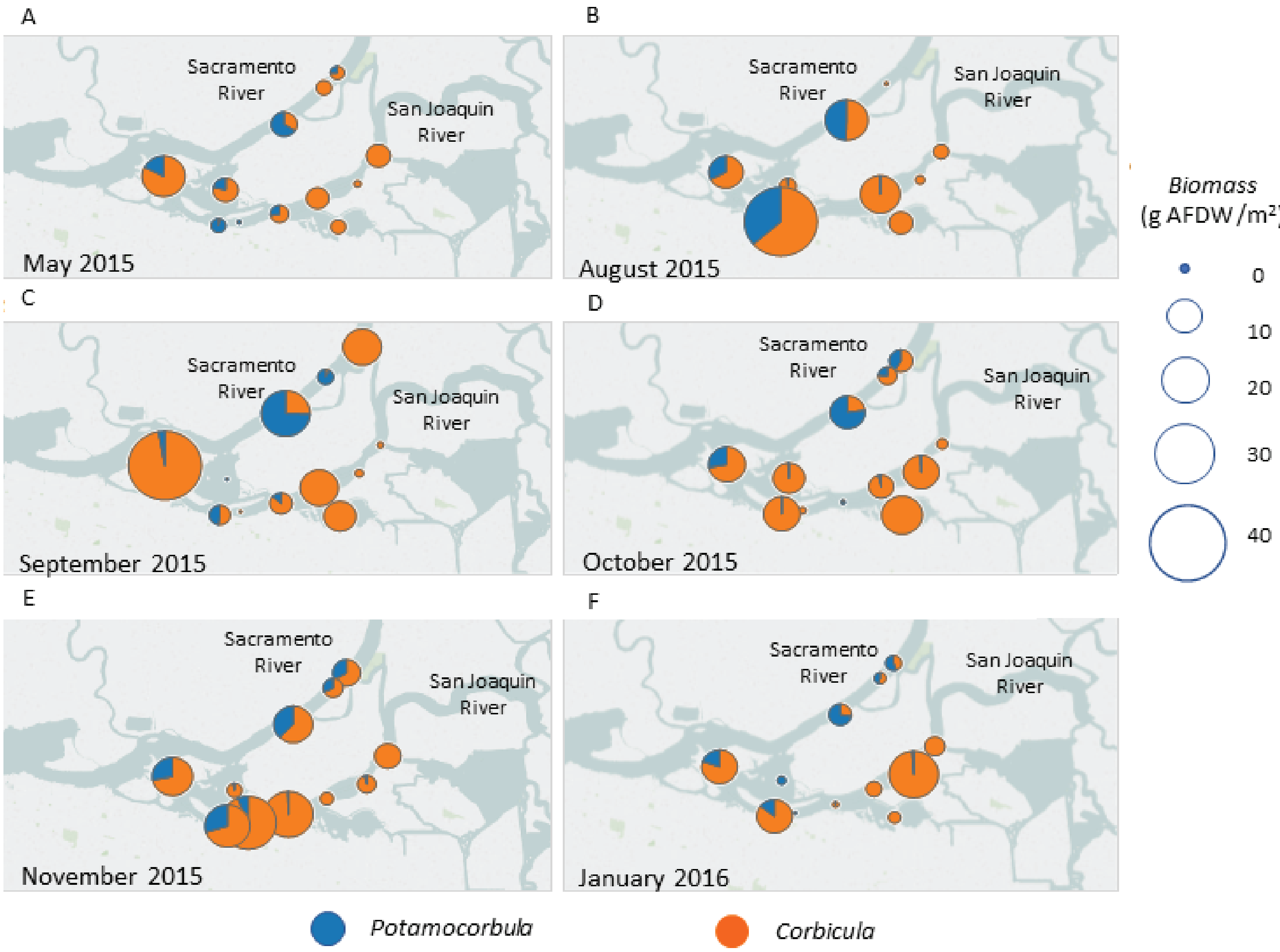


**Figure 14.** Biomass (grams ash-free-dry-weight/square meter [g AFDW/m$^2$]) for *Potamocorbula* and *Corbicula* at the three areas where bivalves were most likely to be influenced by change in salinity as a result of the barrier placement (confluence, San Joaquin River, and Sacramento River sampling stations shown in fig. 1). Data are from the Sacramento–San Joaquin River Delta, California, during the period immediately after the barrier placement and after its removal, May 2015–January 2016.

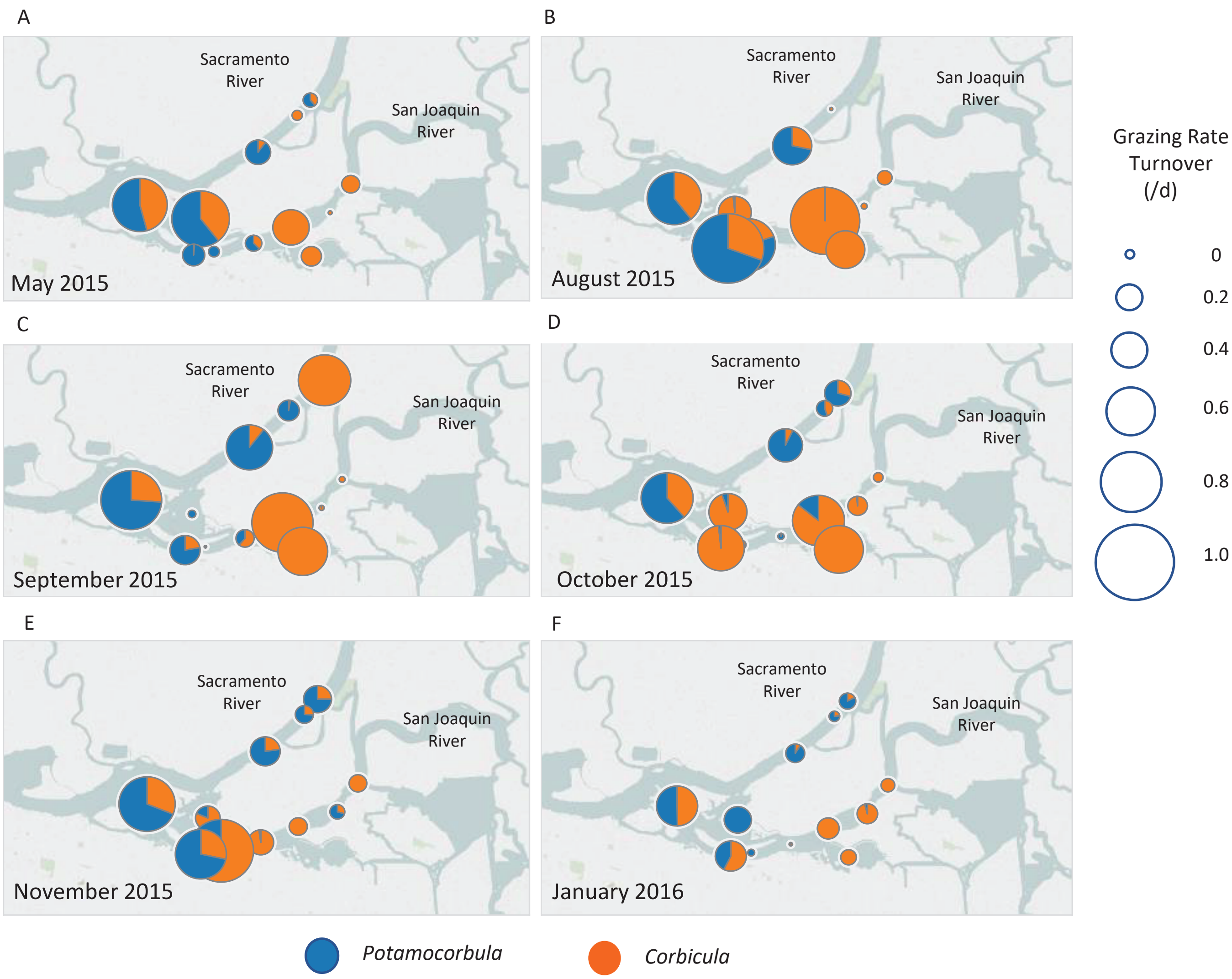


**Figure 15.** Grazing rate turnover (number of times the water column was turned over) per day (/d) for *Potamocorbula* and *Corbicula* at the three areas where bivalves were most likely to be influenced by change in salinity as a result of the barrier placement (confluence, San Joaquin River, and Sacramento River sampling stations shown in fig. 1). Data are from the Sacramento–San Joaquin River Delta, California, during the period immediately after the barrier placement and after its removal, May 2015–January 2016.

## Conclusions

Null hypotheses and the results are as follows:

- $H_0$ *Potamocorbula* will move up the Sacramento and San Joaquin Rivers to locations where the salinity is in the 1–2 $S_P$ range on the bottom. Biomass and grazing rate will increase at specific locations as a function of each species' preferred salinity (*Potamocorbula* 2 or more and *Corbicula* 10 or less)

*Potamocorbula* moved up the Sacramento River with the increasing salinity but moved a shorter distance upriver in the San Joaquin River despite what appeared to be appropriate salinity at Jersey Point (SJJ).

- $H_0$ Adult *Corbicula* will not retreat from their position that was recorded in May 2015.

Adult Corbicula held their May 2015 position in both rivers and the confluence.

- $H_0$ Recruits of *Corbicula* will be limited to salinities of 2 or less $S_P$ and recruits of *Potamocorbula* will settle in areas with salinities 2 or more $S_P$.

*Corbicula* recruits did not settle into areas on the Sacramento River that should have had acceptable salinities for at least part of each day. *Potamocorbula* recruits did not settle upriver of Big Break even though salinities were favorable, and adults were found up-river of this location.

- $H_0$ Both bivalve species will increase their growth rate in areas with increased water column residence times and increased primary production. Grazing rates will increase as the bivalve biomass increases in these areas.

There was no indication that primary production increased in areas where this hypothesis could be tested.

- After Barrier Removal: $H_0$ Adult Potamocorbula will remain in locations that receive some water with salinities 1 or more $S_P$. *Corbicula* adults will maintain their position if the salinity is 10 or less $S_P$.

*Potamocorbula* remained at the upper end of Decker Island through January 2016 but receded to Sherman Lake on the San Joaquin River. *Corbicula* did not move.

- After Barrier Removal: $H_0$ *Corbicula* recruits will settle in areas with a salinity of 2 or less $S_P$, whereas *Potamocorbula* will settle in areas with a salinity of 2 or more $S_P$.

*Potamocorbula* recruits were only found downstream from Decker Island at the end of January 2016 when the salinity was very low at the upstream stations. *Corbicula* recruits decline down-bay of Big Break, possibly in response to increasing salinity in December and January (fig. 5; SJJ in fig. 1).

## References Cited


Cole, B.E., Thompson, J.K., and Cloern, J.E., 1992, Measurement of filtration rates by infaunal bivalves in a recirculating flume: Marine Biology, v. 113, no. 2, p. 219–225, https://doi.org/10.1007/BF00347274.

Department of Water Resources (DWR), 2020, California data exchange center: California Department of Water Resources website accessed April, 2016 at https://cdec.water.ca.gov/index.html.

Foe, C., and Knight, A., 1986, A method for evaluating the sublethal impact of stress employing *Corbicula fluminea, in* Britton, J.C., ed., Proceedings of the Second International Corbicula Symposium: American Malacological Bulletin Special Edition No. 2, Hattiesburg, Mississippi, p. 133–142.

Kimmerer, W.J., Gartside, E., and Orsi, J., 1994, Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay: Marine Ecology Progress Series, v. 113, p. 81–93, https://doi.org/10.3354/meps113081.

Kimmerer, W.J., and Lougee, L., 2015, Bivalve grazing causes substantial mortality to an estuarine copepod population: Journal of Experimental Marine Biology and Ecology, v. 473, p. 53–63, https://doi.org/10.1016/j.jembe.2015.08.005.

Kimmerer, W., and Thompson, J., 2014, Phytoplankton growth balanced by clam and zooplankton grazing and net transport into the low-salinity zone of the San Francisco Estuary: Estuaries and Coasts, v. 37, no. 5, p. 1202–1218, https://doi.org/10.1007/s12237-013-9753-6.

Lopez, C.B., Cloern, J.E., Schraga, T.S., Little, A.J., Lucas, L.V., Thompson, J.K., and Burau, J.R., 2006, Ecological values of shallow-water habitats—Implications for restoration of disturbed ecosystems: Ecosystems, v. 9, no. 3, p. 422–440, https://doi.org/10.1007/s10021-005-0113-7.

Lucas, L.V., Cloern, J.E., Thompson, J.K., and Monsen, N.E., 2002, Functional variability of habitats within the Sacramento–San Joaquin Delta—Restoration implications: Ecological Applications, v. 12, p. 1528–1547.

Lucas, L.V., and Thompson, J.K., 2012, Changing restoration rules—Exotic bivalves interact with residence time and depth to control phytoplankton productivity: Ecosphere, v. 3, no. 12, 26 p., https://doi.org/10.1890/ES12-00251.1.

O'Riordan, C.A., Monismith, S.G., and Koseff, J.R., 1995, The effect of bivalve excurrent jet dynamics on mass transfer in a benthic boundary layer: Limnology and Oceanography, v. 40, no. 2, p. 330–344, https://doi.org/10.4319/lo.1995.40.2.0330.

Shrader, K.H., Zierdt Smith, E.L, Parchaso, F., Thompson, J.K., 2020, Benthic community and bivalve metrics data in the Sacramento–San Joaquin Delta from 2015 to 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P9JJOL3W.

Sommer, T., Armor, C., Baxter, R., Breuer, R., Brown, L., Chotkowski, M., Culberson, S., Feyrer, F., Gingras, M., Herbold, B., Kimmerer, W., Mueller-Solger, A., Nobriga, M., and Souza, K., 2007, The collapse of pelagic fishes in the upper San Francisco Estuary: Fisheries, v. 32, no. 6, p. 270–277, https://doi.org/10.1577/1548-8446(2007)32[270:TCOPFI]2.0.CO;2.

Stewart, A.R., Luoma, S.N., Schlekat, C.E., Doblin, M.A., and Hieb, K.A., 2004, Food web pathway determines how selenium affects aquatic ecosystems—A San Francisco Bay case study: Environmental Science & Technology, v. 38, no. 17, p. 4519–4526, https://doi.org/10.1021/es0499647.

Thompson, J.K., Koseff, J.R., Monismith, S.G., and Lucas, L.V., 2008, Shallow water processes govern system-wide phytoplankton bloom dynamics—A field study: Journal of Marine Systems, v. 74, no. 1-2, p. 153–166, https://doi.org/10.1016/j.jmarsys.2007.12.006.

Western Vision Software, 2010, HLImage++, version 6.2: Western Vision Software, accessed October, 2015 at https://www.wvision.com/hlimage.html.

Zierdt Smith, E.L, Parchaso, F., Thompson, J.K., 2021, A spatially and temporally intensive sampling study of benthic community and bivalve metrics in the Sacramento–San Joaquin Delta, 2007–18: U.S. Geological Survey data release, https://doi.org/10.5066/P93BAY64.

# Appendix 1. Number of samples taken in each geographic area (2007–15) and hydrologic year designations (2006–15)

**Table 1.1.** Number of samples taken in each geographic area as part of the California Department of Water Resources Generalized Random Tessellation Stratified design study sampling program, Sacramento–San Joaquin River Delta, California. 2007–15.

| Geographic area | 2007 | | 2008 | | 2009 | | 2010 | | 2011 | | 2012 | | 2014 | | 2015 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May | Oct | May | Oct | May | Oct | May | Oct | May | Oct | May | Oct | May | Oct | May | Oct |
| San Pablo bay | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 8 | 7 | 7 |
| Suisun Bay | 15 | 15 | 17 | 18 | 15 | 17 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 18 | 22 |
| Grizzly Bay | 8 | 7 | 6 | 6 | 7 | 7 | 7 | 7 | 5 | 5 | 7 | 7 | 7 | 7 | 6 | 6 |
| Suisun Marsh | 13 | 13 | 14 | 14 | 12 | 13 | 13 | 13 | 12 | 12 | 15 | 15 | 12 | 12 | 12 | 13 |
| Honker Bay | 8 | 8 | 5 | 5 | 8 | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 7 | 7 | 9 | 5 |
| Confluence | 21 | 21 | 22 | 22 | 20 | 21 | 18 | 18 | 17 | 17 | 15 | 14 | 21 | 25 | 15 | 13 |
| SR South | 7 | 7 | 7 | 7 | 7 | 8 | 7 | 7 | 12 | 12 | 7 | 9 | 9 | 9 | 10 | 10 |
| SR North | 8 | 8 | 8 | 8 | 9 | 16 | 15 | 15 | 13 | 13 | 16 | 16 | 10 | 11 | 8 | 8 |
| NE Sloughs | 10 | 10 | 7 | 7 | 9 | 10 | 9 | 9 | 8 | 8 | 10 | 10 | 7 | 7 | 10 | 10 |
| East Sloughs | 10 | 10 | 11 | 10 | 6 | 8 | 10 | 10 | 9 | 8 | 9 | 9 | 9 | 9 | 12 | 12 |
| SJR West | 9 | 9 | 6 | 6 | 9 | 13 | 10 | 10 | 14 | 14 | 9 | 8 | 8 | 8 | 10 | 12 |
| SJR Central | 9 | 9 | 10 | 10 | 8 | 10 | 12 | 12 | 10 | 10 | 15 | 15 | 10 | 10 | 10 | 10 |
| SJR East | 16 | 14 | 16 | 17 | 15 | 21 | 17 | 17 | 16 | 16 | 18 | 19 | 12 | 12 | 15 | 15 |
| SJR Far East | 2 | 2 | 0 | 0 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 |
| Old River | 9 | 9 | 12 | 11 | 13 | 13 | 10 | 11 | 13 | 13 | 7 | 7 | 14 | 14 | 10 | 10 |
| Middle River | 8 | 9 | 13 | 11 | 11 | 11 | 13 | 13 | 9 | 9 | 14 | 14 | 8 | 8 | 13 | 13 |
| Franks Tract | 11 | 11 | 10 | 10 | 12 | 12 | 10 | 10 | 11 | 11 | 11 | 11 | 10 | 10 | 8 | 8 |
| Mildreds Island | 8 | 8 | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 4 | 4 |

**Table 1.2.** Hydrologic year designation for years of California Department of Water Resources Generalized Random Tessellation Stratified design study, Sacramento–San Joaquin River Delta, California, 2006–15.

| Year | Sacramento Valley index | San Joaquin Valley index |
|---|---|---|
| 2006 | Wet | Wet |
| 2007 | Dry | Critically dry |
| 2008 | Critically dry | Critically dry |
| 2009 | Dry | Dry |
| 2010 | Below normal | Above normal |
| 2011 | Wet | Wet |
| 2012 | Below normal | Dry |
| 2013 | Dry | Critically dry |
| 2014 | Critically dry | Critically dry |
| 2015 | Critically dry | Critically dry |

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