RMP
REGIONAL MONITORING PROGRAM FOR WATER QUALITY IN SAN FRANCISCO BAY

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Selenium Concentrations in Water and Clams in North San Francisco Bay, 2019-2020

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Executive Summary

The Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) started implementing a new design for North Bay selenium (Se) sampling in 2019 after a long-term USGS program was terminated in 2017. To determine if the RMP sampling and analysis methods are producing similar results to the USGS study, we compared Se concentrations and stable isotope values in clams at two stations in Suisun Bay, California, that were sampled by the USGS long-term monitoring program from 1995-2010 and the RMP in 2019-2020. We also compared Se concentrations in water (dissolved and particulate) from the RMP Status and Trends sampling in Suisun Bay (1993-2019) to the samples collected as part of this study.

Spatial patterns in clam Se concentrations between the USGS and RMP studies were similar, with lower concentrations at Station 4.1 (Suisun Bay) than at Station 8.1 (Carquinez Strait). Se concentrations at both stations were consistently lower for the RMP samples than those reported in the long-term USGS dataset. Stable isotope values for $\delta^{13}C$ and $\delta^{15}N$ were similar for the USGS and RMP samples with $\delta^{13}C$ and $\delta^{15}N$ more enriched at Station 8.1 than 4.1. However, there was not close alignment of the RMP samples to the USGS long-term average, particularly at Station 8.1. Average dissolved Se concentrations in water were consistently lower than the long-term average at Station 4.1 and similar to or above the long-term RMP Status and Trends (S&T) average at Station 8.1. Particulate Se concentrations at Stations 4.1 and 8.1 were nearly one-third of the long-term S&T average in Suisun Bay, likely due to a change in methods for calculating particulate Se.

Additional information is needed to evaluate whether the lower Se concentrations measured in clams as part of the RMP study could be suggestive of declining Se concentrations in North Bay clams between 2010 and 2019 or an artifact of the new analytical lab. Additional data from samples collected by the USGS from 2011-2017 should be examined to fill the gap between the datasets. Continued RMP monitoring will also be valuable in evaluating long-term trends.

Introduction

Selenium (Se) is a naturally occurring trace element that is essential for cellular function in plants and animals but is also toxic to aquatic life at levels minimally higher than what is essential. Se enters San Francisco Bay (Bay) from a broad range of pathways, including rivers, stormwater, municipal and industrial wastewater, and atmospheric deposition. The two largest inputs are from the San Joaquin River and oil refinery discharge (Cutter and Cutter 2004), both of which are pathways into northern San Francisco Bay (San Pablo Bay and Suisun Bay). Se export from the San Joaquin River watershed is high due to the geology of the region (marine shales and fossilized marine biota) and agricultural practices that concentrate Se and transport Se-rich sediment to surrounding waterways. The amount of Se delivered to the Bay via the San Joaquin River is highly variable and dependent on the amount and intensity of annual rainfall. The Se input from the five oil refineries in North Bay is delivered to the Bay through the wastewater produced during the processing of fossil fuels (e.g., crude oil), which are derived from living organisms and therefore contain Se. The oil refineries in the North Bay discharge a relatively consistent load of Se within and between years based on oil production levels.

Se toxicity in aquatic animals mainly occurs via consumption of contaminated prey rather than uptake from the water column (Luoma et al. 1992). In the Bay, the invasive overbite clam, *Potamocorbula amurensis,* accumulates Se at a higher rate than native clams (Linville et al. 2002). The spread of this invasive clam and its efficient uptake of Se is largely responsible for the accelerated bioaccumulation of Se in the food web, particularly for bird and fish species that feed on *Potamocorbula*, such as white sturgeon and surf scoters (Stewart et al. 2004).

North San Francisco Bay was identified as being impaired for Se in the 1998 303(d) list based on elevated concentrations in diving ducks (Ohlendorf et al. 1986); human health consumption advisories were first issued in 1987 (CDFW 1991). As a result of management actions taken following the 303(d) listing, Se loading from the Delta decreased one-half to two-thirds between the mid-1990s and mid-2000s in large part due to changes in agricultural practices in the San Joaquin Valley that reduced subsurface drainage and surface runoff of Se to irrigation channels. In the late 1990s, loading from the Bay Area refineries decreased 75% due to Se-removal measures added to the wastewater treatment process (Baginska 2015).

The discovery of high Se concentrations in a wide range of aquatic species (Ohlendorf et al. 1986, Ohlendorf et al. 1991, CDFW 1991) prompted the establishment of a U.S. Geological Survey (USGS) long-term monitoring program for *Potamocorbula* in North Bay that ran from 1995 to 2017 (Linville et al. 2002, Kleckner et al. 2010, Stewart et al.

2013). Clams were collected monthly at two North Bay stations, one near the Delta inflow at the eastern edge of Suisun Bay and the other near the Carquinez Strait area where four oil refineries discharge wastewater into the Bay (Figure 1). Samples were analyzed for Se throughout the time series and for stable isotopes and elemental concentrations of carbon and nitrogen beginning in 1999.

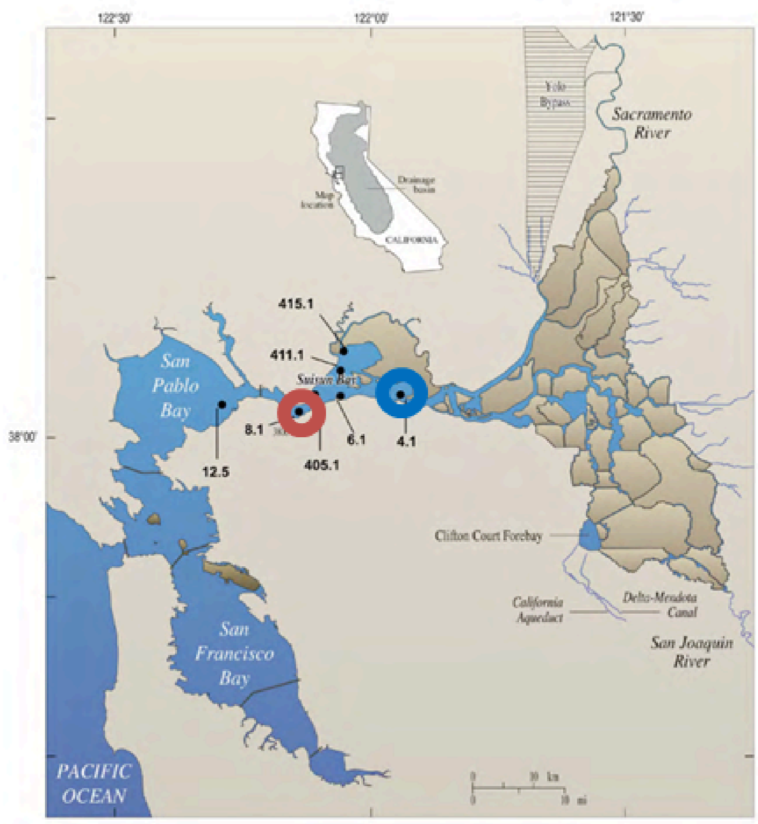

Figure 1. Location of the two sampling locations in Suisun Bay most frequently sampled by the USGS for clams and continued by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). Station 4.1 is near the Delta inflow to the Bay and station 8.1 is close to the wastewater discharge locations of four oil refineries. Figure adapted from Kleckner et al. (2010).

Funding for the USGS monitoring program was terminated in early 2017; sampling continued for an additional six months with funding from the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). The RMP started a more-limited sampling program in June 2019 based on the North Bay monitoring design for water, clams, and white sturgeon (*Acipenser transmontanus*) developed by Grieb et al. (2018). Although the TMDL target for Se in North San Francisco Bay is based on tissue concentration in white sturgeon (Baginska 2015), the USGS and RMP monitoring programs focused on *Potamocorbula* because they are easier to reliably collect than sturgeon, provide information on spatial variation, and, as a major food source for sturgeon, provide information about expected concentrations in sturgeon tissue. The RMP analyzes a small number of white sturgeon samples from all regions of the Bay every five years as part of the Status and Trends Program (e.g., Buzby et al. 2021). In addition, North Bay-specific white sturgeon sampling occurred in 2015-2017 at Sturgeon Derby events (Sun et al. 2019a) and in collaboration with the California Department of Fish and Wildlife (Sun et al. 2019b). Sturgeon tissue monitoring was hampered by the pandemic and other logistical constraints from 2019-2022; limited sampling occurred in 2023.

The purpose of this report is to compare the first two years of clam data collected by the RMP (2019-2020) to the long-term data collected by the USGS for Se (1995-2010; Kleckner et al. 2010) and the stable isotopes of carbon and nitrogen (1999-2010). There was extensive coordination between the RMP and USGS to ensure comparable sampling and analysis methods were used, but differences in personnel and analytical laboratories remained a potential source of variability in the time series. Water data from 2019-2020 are also presented and compared to historical data from the RMP Status and Trends (S&T) monitoring in North Bay (https://cd3.sfei.org/) because the USGS program did not consistently monitor water. The RMP S&T stations did not directly overlap with the Se sampling locations chosen for this study, but were located throughout Suisun Bay.

Methods

Clam tissue interlaboratory comparison

With the termination of the USGS Se monitoring program, samples collected by the RMP had to be analyzed by a different analytical lab than the 1995-2010 Se samples. The USGS samples were analyzed in-house using either hydride generation atomic absorption spectroscopy (HGAAS, through mid-2001) or isotope dilution-hydride generation-ICPMS (Kleckner et al. 2017). To find a lab that could prepare and analyze clam tissue samples for Se and produce similar results to the USGS, the RMP conducted an interlaboratory comparison between four laboratories using archived clam tissue. The criteria used to select the lab included: 1) precision (internal consistency on lab replicates); 2) recovery relative to the intercomparison mean; 3) recovery relative to the historical value measured by the USGS; 4) CRM performance (recovery relative to CRMs or other external standards); 5) California Environmental Data Exchange Network (CEDEN) reporting ability; 6) communication and timely reporting; and 7) cost (less than 10% over mean). The greatest weight was given to precision and recovery results, followed by CRM performance. Based on these criteria, Brooks Applied

Laboratories (BAL) was selected to perform Se analysis in clams and water for the RMP study (RMP 2019).

Clam sampling and analysis

Due to funding constraints, the RMP was not able to support year-round monthly monitoring of clams and water. Based on historical data and management needs, the RMP developed a reduced sampling plan. The plan recommended sampling in two, three-month blocks for a total of six sampling events per year (Grieb et al. 2018; Table 1). For each project year, the first sampling block occurred from June-August and the second from December-February. These months were chosen for water and clam sampling because they preceded the California Department of Fish and Wildlife (CDFW) sturgeon tagging and muscle plug collections (autumn) and spawning season (spring) by 2-3 months (Table 1), the average lag time for Se in food (clams) to be incorporated into tissue for sturgeon (Beckon 2016). For 2019, samples were collected as recommended, in each of the six months. However, samples from the first two events (June and July) were not dried properly by the lab, resulting in tissue data that were rejected during our QA/QC process (Table A1). For the 2020 sampling effort, samples were only collected in July, August, January, and February due to constraints of the Covid-19 pandemic.

Table 1. Timing of sample collection for the RMP study (clams and water) in relation to sturgeon tissue collection and spawning. Project year in this report includes samples collected from June-February, with the year corresponding to when sampling began.

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Clams	RMP collection						RMP collection					
Water												
Sturgeon			CDFW collection							Spawning		

During each sampling event, approximately 100 clams, ranging in size from 8-20 mm, were collected from each station using a clam dredge. Clams were stored in chilled site water while in the field. In the lab, clams were allowed to depurate for at least 48 hours in filtered (0.45 µm), recirculating, 10°C water from the collection site. Clams were then separated into five size classes (generally 8-9 mm, 10-11 mm, 12-13 mm, 14-16 mm, 17-20 mm) and frozen at -80°C and shipped to BAL for analysis. Clam tissue was removed from the shells and dried at a constant temperature of 21°C (Brown and Luoma 1995). This low temperature drying method resulted in the growth of mold on the clam tissue collected in June and July 2019, so the drying method was changed to freeze drying in 2020, following the methods of Kleckner et al. (2010).

Clam tissue was analyzed for Se by BAL in Seattle, Washington. Samples were analyzed using triple quadrupole inductively-coupled plasma mass spectroscopy ICPMS-QQQ-MS (EPA method 6020).

Stable isotopes of carbon ($\delta^{13}C$ compared to the Vienne Pee Dee Belemnite [VPDB] standard) and nitrogen ($\delta^{15}N$ compared to the atmospheric nitrogen standard) in clam tissues were also measured as part of the USGS and RMP studies to assess variability in food sources and source water. For the RMP study, dried clam tissue was sent to the University of California Davis Stable Isotope Facility (SIF) in Davis, California, where samples were analyzed for elemental concentrations and stable isotopic composition of carbon and nitrogen using an elemental analyzer interfaced to a continuous flow infrared mass spectrometer (IRMS). BAL did not have the equipment to finely grind the samples and there was concern that too much sample mass would be lost in the process, so chunks of dried tissue were placed into tin capsules by SIF staff for analysis.

Water sampling and analysis

At each station, two 4 L grab samples were collected from 1 m below the surface. For the dissolved fraction, water was filtered through a 0.45 um Voss capsule filter cartridge using a peristaltic pump. Particulate samples were obtained by filtering at least 350 mL of sample water through a 0.4 um Nuclepore Polycarbonate Track-Etched Membrane filter using a portable vacuum pump. Lab blanks and field duplicates were collected during each block of sampling. Se concentrations were quantified for dissolved and particulate samples using column separation coupled with an ICPMS (BAL in-house method).

Results

Clams

We compared average Se concentration (ug/g dw) and stable isotopes of carbon and nitrogen across clam size classes from the USGS (1995-2010) and RMP (2019-2020) sampling programs for the months that were included in the RMP sampling plan (Project year includes June-August and December-February, with year aligning with the beginning of sampling) to determine if the RMP sampling and analysis approaches were adequately replicating the USGS monitoring program.

Similar to the USGS time series, clam Se concentrations during the RMP study were consistently lower at Station 4.1 (Suisun Bay) than at Station 8.1 (Carquinez Strait) (Figure 2; Tables A1, A2). Se concentrations at both stations were consistently lower for the RMP samples than those reported in the long-term USGS dataset (Figure 2). Seasonal patterns were similar for the two efforts, but there was more variance around the mean for the RMP sampling due to the small sample sizes. For both datasets, there was more seasonal variability at Station 4.1 than 8.1, with higher Se concentrations tending to occur during July and December.

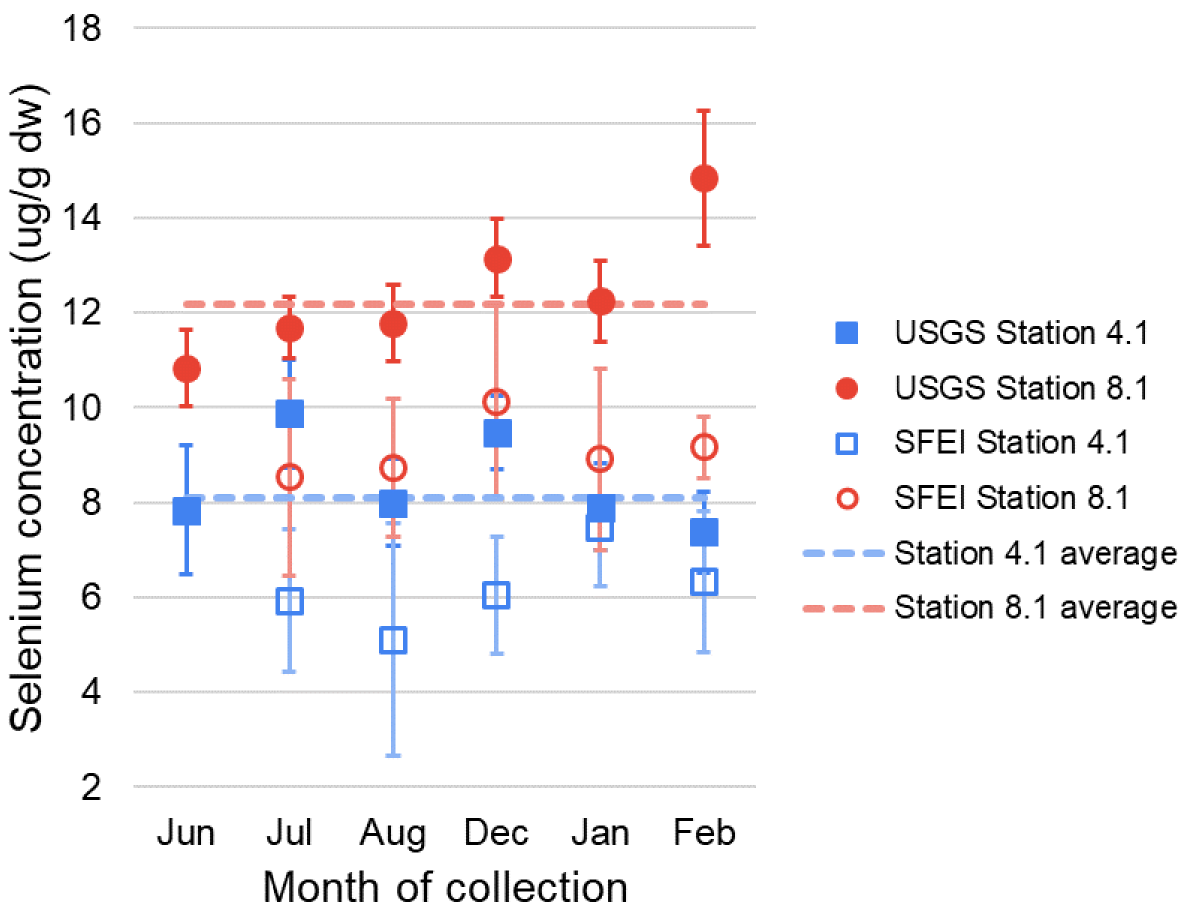

Figure 2. Average monthly selenium concentration in clam tissue (ug/g dw; +/- 2 SE) for Stations 4.1 (blue) and 8.1 (red) for the USGS (1995-2010; solid shapes) and RMP samples (2019-2020; open shapes). Dotted lines denote the annual mean from the USGS time series for Stations 4.1 (blue) and 8.1 (red).

Mean Se concentrations in the USGS dataset (Kleckner et al. 2010) were highly variable across years (Figure 3). Concentrations tended to be lower during high Delta inflow years (e.g., 2003-2006) when dilution was high (Stewart et al. 2013) and water residence time was likely shorter. For Station 4.1, average Se concentration from the

USGS samples was 8.09 ug/g dw, while the RMP average was 5.52 ug/g dw. For Station 8.1, the USGS average was 12.16 ug/g dw and the RMP average was 6.62 ug/g dw (Figure 2).

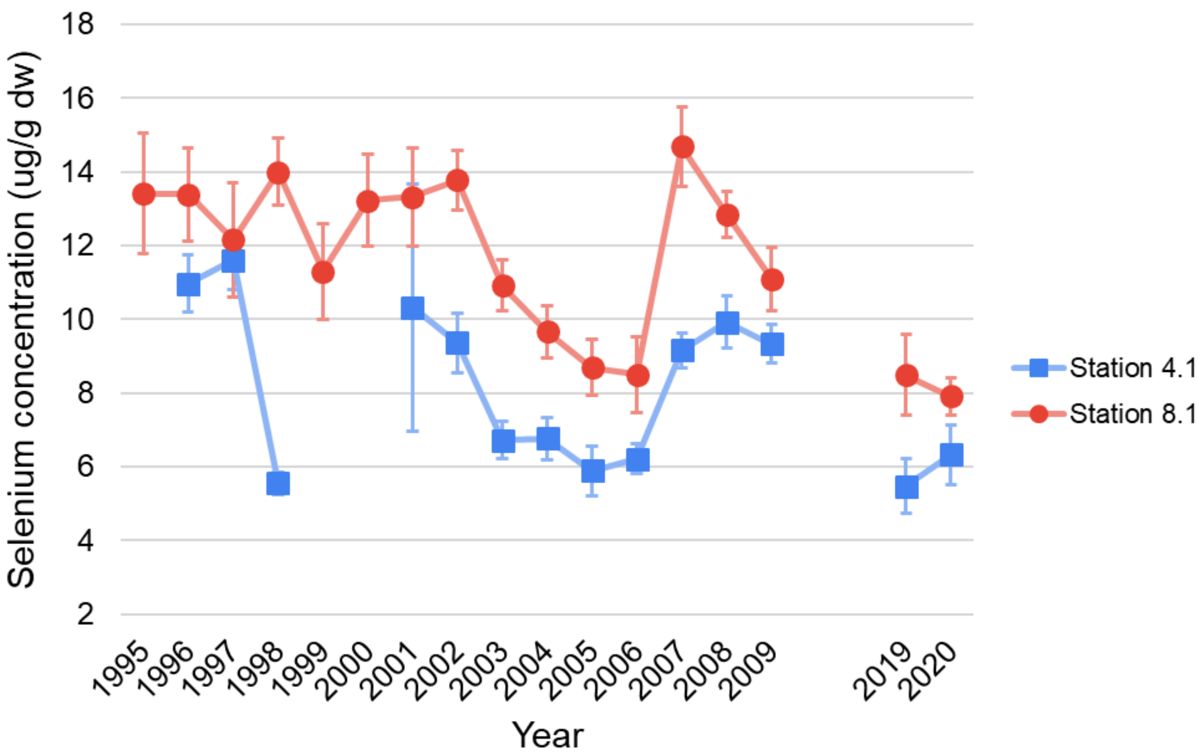

Figure 3. Annual average Se concentrations in clam tissue (ug/g dw; +/- 2 SE) for Stations 4.1 (blue) and 8.1 (red) for the USGS (1995-2009, approximately monthly year-round; Kleckner et al. 2010) and RMP (2019-2020, June-August and December-February) collections.

Stable isotope results from the RMP study were only available for August and December through February for Project Year 2019 (June 2019-February 2020) and the last two months only for Project Year 2020 (January and February 2021). The clam tissue from June and July 2019 was compromised in the drying process and isotope results were flagged during the Quality Assurance/Quality Control process (QA summary). In July 2020, there was not enough remaining tissue after Se analysis for stable isotope analysis.

Based on these limited results, the $\delta^{13}C$ and $\delta^{15}N$ (‰) isotope values for the RMP study showed similar patterns to the USGS data with $\delta^{13}C$ and $\delta^{15}N$ more enriched at Station 8.1 than 4.1 (Figure 4, Tables A3 and A4). However, there was not close alignment of the RMP samples to the USGS long-term average. At Station 4.1, $\delta^{13}C$ and $\delta^{15}N$

isotopic values measured as part of the RMP study were similar to the long-term USGS average in summer and winter 2019 but lower for $\delta^{15}N$ in winter 2020. RMP $\delta^{13}C$ and $\delta^{15}N$ values for Station 8.1 were not as similar to the USGS long-term average, particularly for carbon. The $\delta^{13}C$ values were 1-2‰ lower in the RMP samples than the USGS samples.

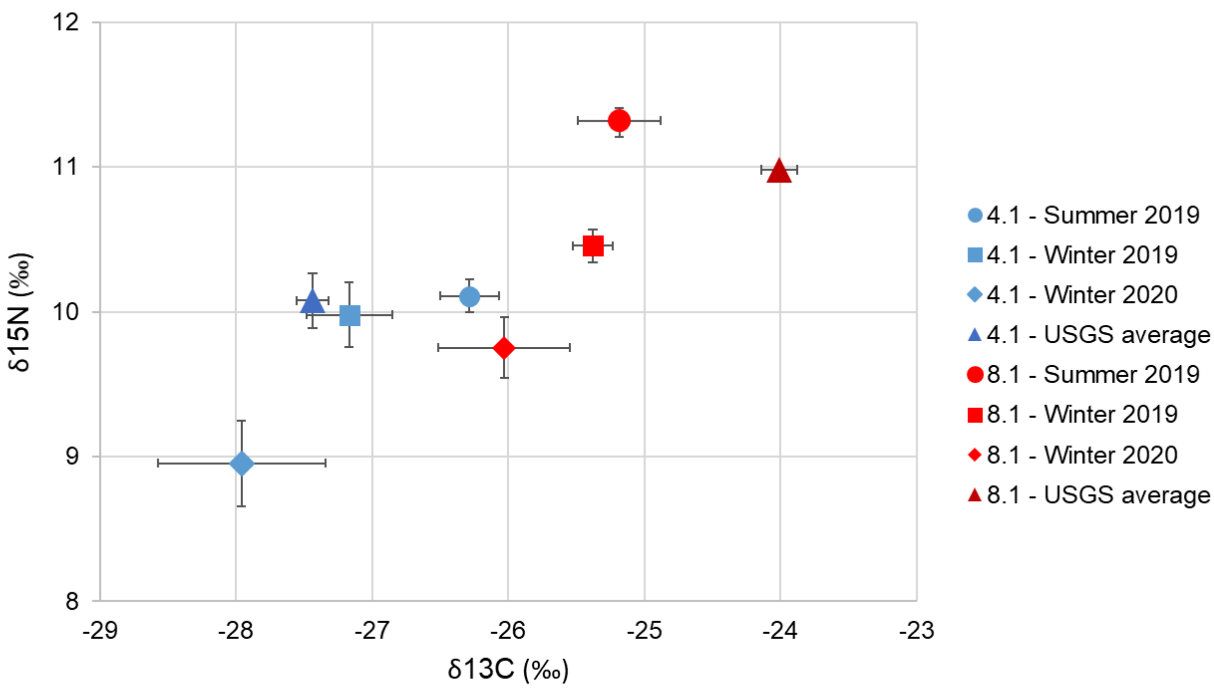

Figure 4. Average clam tissue stable isotope values for δ13C and δ15N (‰, +/- 2 SE) for summer 2019 (Aug only) and winter 2019 (Dec-Feb) and 2020 (Jan-Feb) sampling periods, along with the long-term USGS means for Stations 4.1 (blue) and 8.1 (red) for 1999-2010 (Kleckner et al. 2010).

Water

Dissolved Se concentration in water was slightly lower at Station 4.1 than Station 8.1 (Figure 5), similar to clam Se concentrations. Because no USGS long-term data were available for comparison, we used the RMP Status and Trends (S&T) data from stations throughout Suisun Bay from 1993-2019 to calculate the long-term average (n = 123; 0.125 ug/L). Average dissolved Se concentrations were consistently lower than the long-term average at Station 4.1 and similar to or above the long-term average at Station 8.1 (Figure 5). The two stations had similar seasonal variability in dissolved Se concentration with the lowest values in June and peaks in July and February.

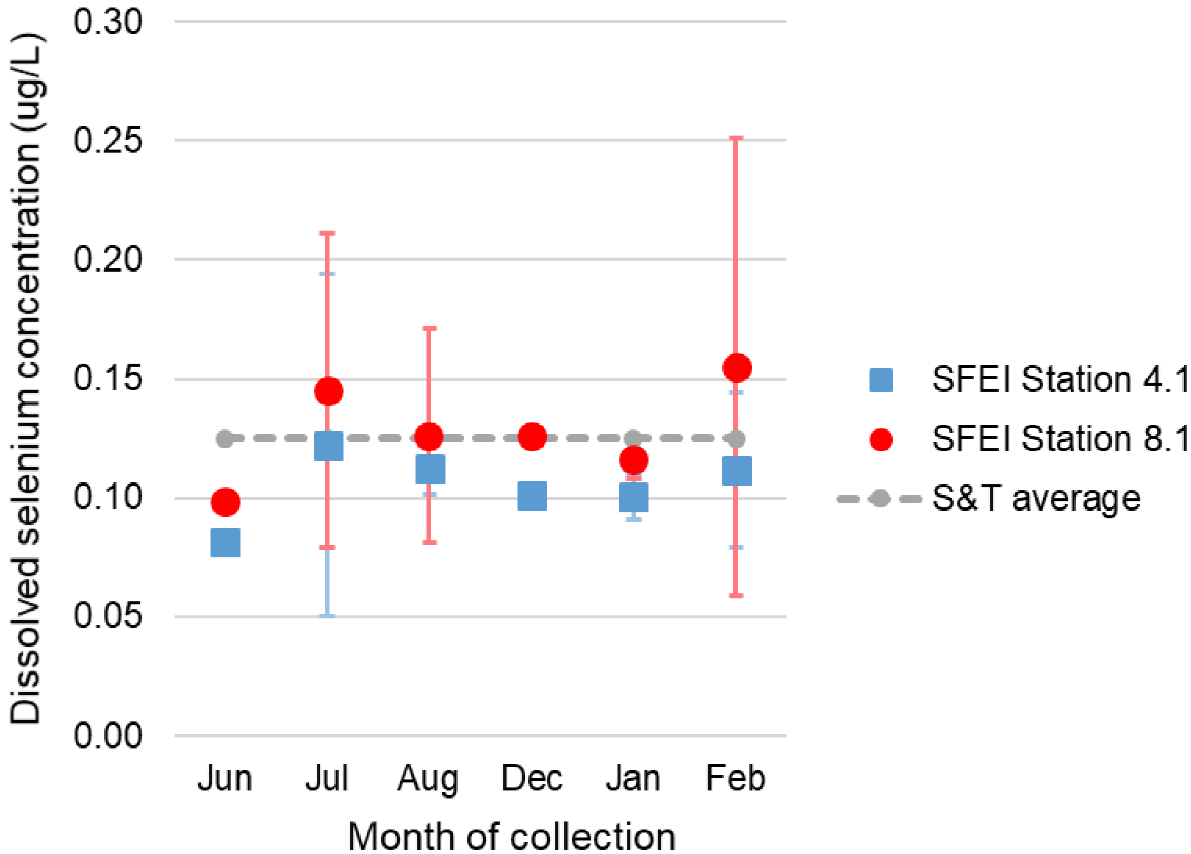

Figure 5. Average (+/- 2 SE) dissolved selenium concentration in water at SFEI Stations 4.1 and 8.1 (2019-2020) compared to the long-term average (1993-2019) of dissolved selenium concentrations at RMP Status and Trends (S&T) stations throughout Suisun Bay.

Particulate Se concentrations at Stations 4.1 and 8.1 were nearly one-third of the long-term average in Suisun Bay (n = 88 from 1993-2019; average = 0.038 ug/L; Figure 6). The S&T average particulate Se concentration was calculated by subtracting the dissolved concentration from the total Se concentration for samples collected from 1993-2015. This method is an imprecise way of estimating particulate Se, so the RMP started measuring particulate concentration directly in 2017 (same method as Se study methods). Dissolved Se is the dominant form of Se in the estuary (91% at Station 4.1 and 93% at Station 8.1 based on 2019 and 2020 data only), with concentrations nearly an order of magnitude higher than particulate Se. Particulate Se values were similar at the two stations, but in four of the six months, concentrations were slightly higher at Station 4.1 than 8.1 (Figure 6), a departure from the dissolved water and clam data (Figures 3 and 5).

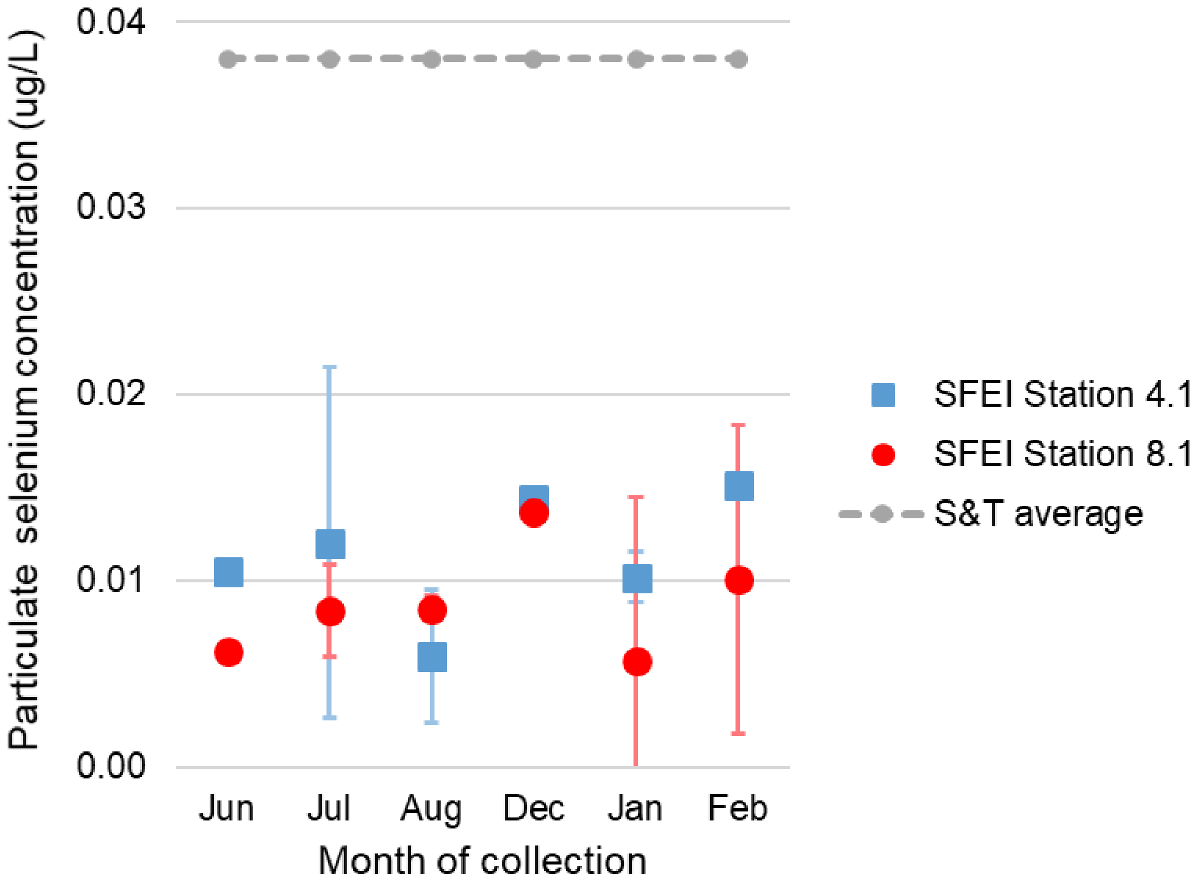

Figure 6. Average (+/- 2 SE) particulate selenium concentration by month at Stations 4.1 and 8.1 (2019-2020) compared to the long-term average (1993-2019) from RMP Status and Trends stations throughout Suisun Bay.

Discussion

The first two years of clam Se data collected by the RMP showed a similar spatial pattern to the long-term USGS data with concentrations consistently higher in clams collected at Station 8.1 compared to Station 4.1. However, concentrations in the RMP samples were well below the long-term average nearly every month, particularly for Station 8.1 (Figure 2). While there was year-to-year variability in the USGS dataset, the RMP concentrations in 2019-2020 were at the low end of the range of USGS annual averages (Figure 3). Additional information is needed to evaluate whether the lower Se concentrations measured in clams as part of the RMP study could be suggestive of declining Se concentrations in North Bay clams between 2010 and 2019 or an artifact of the new analytical lab. Additional data from samples collected by the USGS from

2011-2017 should be examined to fill the gap between the datasets. Continued monitoring will also be valuable in evaluating long-term trends.

Freshwater flow is one of the major factors affecting Se concentrations in water and biota in the North Bay. Stewart et al. (2013) found that Se concentrations in clams were negatively correlated with freshwater inflow from the Delta (lagged by 60 days). Delta inflow was the third highest (for the period of record for clam monitoring) preceding the 2019 collections, but was lowest preceding the 2020 collections (Figure 7). Based on the relationship with freshwater inflow, Se concentration in 2020 should have been higher than 2019, but this was not clearly evident in the clam data (Figure 3).

Stable isotope values can also be affected by freshwater, particularly for carbon (Stewart et al. 2013). In winter 2020, $\delta^{13}C$ values were lowest suggesting less saline conditions (i.e., less marine influence). This is not consistent with Delta outflow to the Bay during that time, which was low (Figure 7). The winter 2020 $\delta^{15}N$ values for both stations were 1-1.5‰ lower than the long-term average, which could be indicative of a change in phytoplankton quality and/or nitrogen loading and recycling in the system (Cloern et al. 2002). Changes in the isotope values could also indicate a change in diet for the clams, particularly type and size of phytoplankton consumed. It is possible that the non-ground tissue samples used for the RMP analysis resulted in less accurate isotope measurements. The difference in isotope analytical labs cannot be ruled out because there was no archival tissue available for comparative analyses. Data from 2011-2017 would be helpful for assessing if isotope values were changing leading up to the RMP sampling.

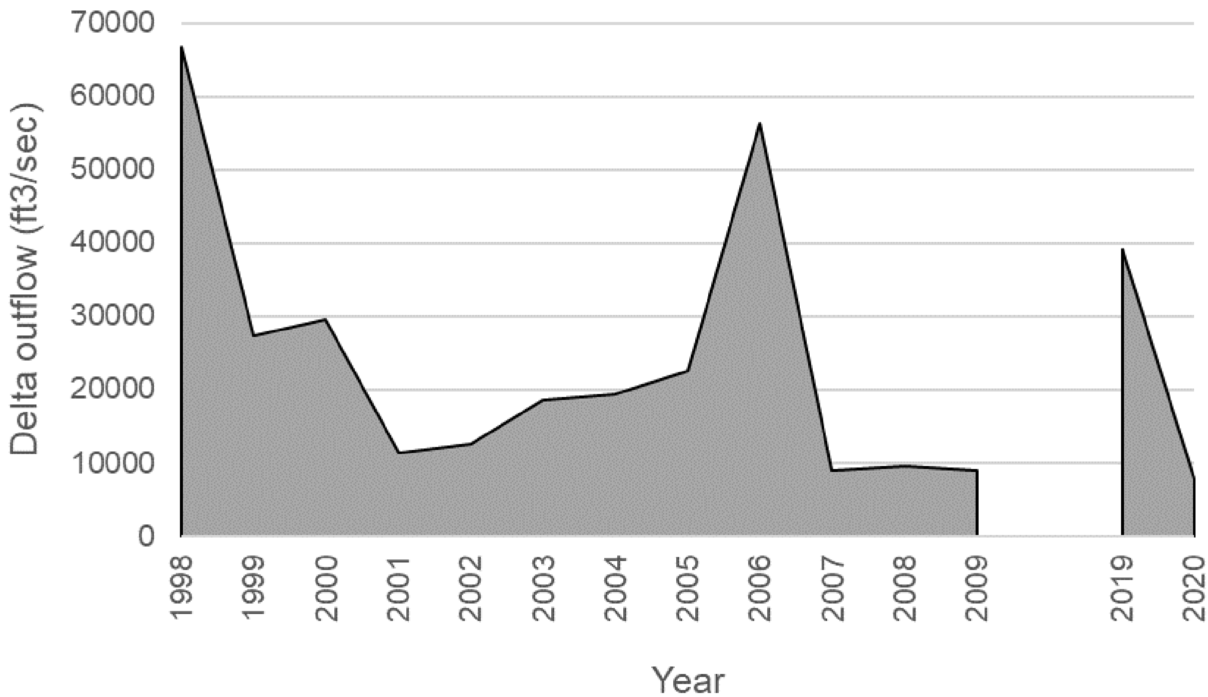

Figure 7. Average Delta outflow (ft^3/sec) by calendar year (https://www.usbr.gov/mp/cvo/pmdoc.html).

Dissolved Se concentrations in water were similar to the long-term average of the RMP samples from Suisun Bay. Particulate concentrations, however, were much lower than the long-term average. This could be due to different analytical techniques used during the time series (i.e., particulate concentrations calculated vs. measured) as well as changes in measurement detection limits over time.

The two years of data examined in this report for the RMP North Bay Se project suggest that the results may not be comparable to the long-term USGS dataset, especially for clams. An additional two years of data have now been collected (2021-2022), which will be useful for determining if changes were likely due to environmental conditions or the new laboratory.

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Appendix

Table A1. Average monthly selenium concentration in clam tissue (ug/g dw; +/- 1 SE) by year for Station 4.1 for the USGS (2001-2010) and RMP samples (2019-2020; shaded gray). USGS data from Kleckner et al. (2010). Project year includes the two sampling periods used for the RMP study, June-August and December-February.

Project year	Jun Ave	Jun SE	Jul Ave	Jul SE	Aug Ave	Aug SE	Dec Ave	Dec SE	Jan Ave	Jan SE	Feb Ave	Feb SE
2001	-	-	-	-	-	-	13.00	1.99	8.20	0.70	7.90	0.12
2002	5.73	0.44	13.00	-	11.33	0.67	10.33	0.67	6.80	0.60	6.63	0.24
2003	-	-	6.53	0.33	6.27	0.13	7.87	0.07	6.10	0.50	6.47	0.55
2004	8.32	0.51	8.50	0.83	8.80	0.75	8.07	0.24	6.23	0.27	4.80	0.64
2005	3.97	0.17	-	-	7.23	0.64	7.83	0.46	7.07	1.15	7.53	1.14
2006	-	-	-	-	4.77	0.37	6.30	0.22	-	-	8.17	0.67
2007	-	-	8.23	1.15	8.93	1.54	11.00	1.15	11.00	2.00	12.00	1.15
2008	12.33	0.67	12.00	-	-	-	11.00	1.15	10.67	0.67	6.50	0.92
2009	8.83	0.13	11.00	1.15	8.63	0.74	9.87	0.13	-	-	-	-
2019	-	-	-	-	7.87	3.21	6.05	1.23	8.34	1.39	6.45	0.36
2020	-	-	5.61	0.47	4.73	2.24	-	-	7.37	0.38	7.33	0.61

Table A2. Average monthly selenium concentration in clam tissue (ug/g dw; +/- 1 SE by year for Station 8.1 for the USGS (1995-2010) and RMP samples (2019-2020; shaded gray). USGS data from Kleckner et al. (2010). Project year includes the two sampling periods used for the RMP study, June-August and December-February.

Project year	Jun Ave	Jun SD	Jul Ave	Jul SD	Aug Ave	Aug SD	Dec Ave	Dec SD	Jan Ave	Jan SD	Feb Ave	Feb SD
1995	-	-	-	-	-	-	16.90	-	15.40	2.21	18.90	0.60
1996	11.60	1.58	11.57	1.57	12.67	2.32	14.77	1.94	-	-	-	-
1997	8.33	1.18	9.60	2.18	12.00	2.63	-	-	-	-	-	-
1998	-	-	-	-	-	-	-	-	12.67	1.33	-	-
1999	9.17	2.73	12.00	2.84	10.43	1.27	-	-	-	-	19.00	1.99
2000	8.47	0.70	10.37	1.34	12.67	1.73	14.40	-	-	-	-	-
2001	10.97	3.04	12.00	1.15	-	-	17.00	-	15.00	1.15	16.33	3.28
2002	13.13	1.44	15.33	0.67	15.67	0.67	14.00	1.15	13.57	0.17	13.80	1.33
2003	12.03	0.24	10.83	0.24	11.93	0.94	10.50	1.17	10.80	1.25	-	-
2004	10.03	1.15	12.03	0.88	10.63	0.29	9.93	0.33	9.57	0.29	6.53	1.15
2005	7.03	0.40	-	-	8.77	0.69	10.60	1.11	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	18.00	2.00
2007	-	-	12.43	3.34	12.07	2.92	16.17	0.33	11.33	1.77	14.67	1.33
2008	14.00	2.00	12.67	1.77	-	-	12.67	1.77	13.33	1.77	13.33	1.33
2009	14.33	0.67	9.77	0.29	10.97	1.21	7.77	0.44	-	-	-	-
2019	-	-	-	-	10.61	1.17	10.11	2.05	10.43	742.94	9.62	0.71

2020	-	-	8.53	0.88	6.88	0.79	-	-	7.39	0.54	8.70	0.42

Table A3. Stable isotope values for δ13C and δ15N in clam tissue (‰; +/- 1 SE) by year for Station 4.1 for the USGS (2001-2010) and RMP samples (2019-2020; shaded gray). USGS data from Kleckner et al. (2010). Project year includes the two sampling periods used for the RMP study, June-August and December-February.

Project year	Isotope	Jun Ave	Jun SE	Jul Ave	Jul SE	Aug Ave	Aug SE	Dec Ave	Dec SE	Jan Ave	Jan SE	Feb Ave	Feb SE
2001	$\delta^{13}C$	-	-	-	-	-	-	-26.50	0.11	-	-	-	-
	$\delta^{15}N$	-	-	-	-	-	-	12.39	0.22	-	-	-	-
2002	$\delta^{13}C$	-26.68	0.03	-26.82	0.13	-26.62	0.31	-26.68	0.18	-25.76	0.95	-27.65	0.07
	$\delta^{15}N$	10.23	0.03	12.13	0.43	11.88	0.06	12.25	0.36	11.57	0.23	10.28	0.08
2003	$\delta^{13}C$	-	-	-27.95	0.06	-27.60	0.04	-27.27	0.00	-27.23	0.03	-27.60	0.16
	$\delta^{15}N$	-	-	10.01	0.10	11.04	0.06	11.07	0.09	10.87	0.10	10.00	0.27
2004	$\delta^{13}C$	-27.17	0.03	-27.16	0.04	-26.71	0.02	-26.92	0.05	-26.97	0.02	-27.32	0.09
	$\delta^{15}N$	10.35	0.06	10.73	0.12	10.81	0.04	10.58	0.11	9.87	0.03	9.19	0.31
2005	$\delta^{13}C$	-29.09	0.08	-	-	-27.80	0.05	-27.35	0.04	-27.29	0.06	-29.09	0.30
	$\delta^{15}N$	7.07	0.10	-	-	9.83	0.02	9.87	0.08	9.33	0.24	8.39	0.20
2006	$\delta^{13}C$	-	-	-	-	-26.73	0.10	-27.74	0.18	-28.04	0.25	-28.07	0.24
	$\delta^{15}N$	-	-	-	-	7.43	0.04	8.85	0.05	8.52	0.21	8.40	0.08
2007	$\delta^{13}C$	-	-	-27.47	0.10	-27.01	0.09	-26.86	0.04	-	-	-27.13	0.05
	$\delta^{15}N$	-	-	9.91	0.06	10.09	0.03	10.08	0.04	-	-	10.16	0.07
2008	$\delta^{13}C$	-26.95	0.09	-26.68	0.05	-	-	-26.92	0.14	-27.33	0.11	-28.34	0.13

	$\delta^{15}N$	11.06	0.15	11.48	0.15	-	-	11.84	0.07	11.51	0.13	9.95	0.13
2009	$\delta^{13}C$	-27.98	0.10	-27.61	0.07	-26.91	0.03	-27.04	0.03	-27.15	0.03	-27.51	0.13
	$\delta^{15}N$	10.00	0.108	10.51	0.05	11.23	0.04	11.47	0.47	10.88	0.14	10.50	0.25
2019	$\delta^{13}C$	-29.63	0.58	-29.58	0.38	-26.29	0.18	-27.17	0.16	-27.69	0.52	-28.24	0.34
	$\delta^{15}N$	12.93	1.13	20.82	2.84	10.11	0.09	9.98	0.11	9.12	0.27	8.78	0.10
2020	$\delta^{13}C$	-	-	-	-	-	-	-	-	-28.35	0.12	-27.58	0.32
	$\delta^{15}N$	-	-	-	-	-	-	-	-	12.73	0.12	12.71	0.30

Table A4. Stable isotope values for δ13C and δ15N in clam tissue (‰; +/- 1 SE) by year for Station 8.1 for the USGS (1999-2010) and RMP samples (2019-2020; shaded gray). USGS data from Kleckner et al. (2010). Project year includes the two sampling periods used for the RMP study, June-August and December-February.

Project year	Isotope	Jun Ave	Jun SE	Jul Ave	Jul SE	Aug Ave	Aug SE	Dec Ave	Dec SE	Jan Ave	Jan SE	Feb Ave	Feb SE
1999	$\delta^{13}C$	-	-	-23.18	0.03	-23.16	0.07	-	-	-23.92	0.13	-24.38	-
	$\delta^{15}N$	-	-	11.04	0.08	11.70	0.08	-	-	9.91	0.14	9.64	-
2000	$\delta^{13}C$	-23.13	0.07	-23.03	0.05	-23.07	0.07	-23.22	-	-	-	-24.12	-
	$\delta^{15}N$	11.24	0.02	10.43	0.21	10.84	0.47	11.09	-	-	-	9.86	-
2001	$\delta^{13}C$	-22.02	0.06	-22.51	0.12	-	-	-23.01	-	-	-	-	-
	$\delta^{15}N$	11.79	0.07	11.83	0.15	-	-	12.41	-	-	-	-	-
2002	$\delta^{13}C$	-23.83	0.05	-26.46	0.03	-24.51	0.80	-24.98	0.95	-25.06	0.92	-25.41	0.16
	$\delta^{15}N$	11.21	0.06	12.27	0.12	12.33	0.04	11.33	0.38	10.40	0.46	10.54	0.50
2003	$\delta^{13}C$	-25.50	0.06	-24.78	0.04	-25.02	0.02	-23.33	0.02	-23.58	0.01	-24.30	0.08

	$\delta^{15}N$	11.83	0.10	11.04	0.03	11.41	0.10	11.71	0.13	11.13	0.02	9.97	0.05
2004	$\delta^{13}C$	-23.73	0.05	-23.73	0.03	-23.00	0.03	-23.01	0.03	-23.06	0.03	-	-
	$\delta^{15}N$	11.13	0.03	11.19	0.02	11.52	0.07	11.04	0.03	10.72	0.09	-	-
2005	$\delta^{13}C$	-25.91	0.09	-	-	-24.76	0.09	-24.13	0.02	-24.30	0.02	-27.68	0.08
	$\delta^{15}N$	10.15	0.08	-	-	10.98	0.07	10.66	0.05	10.45	0.11	8.87	0.06
2006	$\delta^{13}C$	-	-	-	-	-	-	-	-	-	-	-	-
	$\delta^{15}N$	-	-	-	-	-	-	-	-	-	-	-	-
2007	$\delta^{13}C$	-	-	-23.62	0.08	-23.44	0.05	-23.70	0.03	-	-	-24.47	0.06
	$\delta^{15}N$	-	-	10.91	0.05	10.76	0.06	10.16	0.05	-	-	9.88	0.07
2008	$\delta^{13}C$	-24.26	0.10	-24.48	0.11	-	-	-24.15	0.11	-24.67	0.15	-25.49	0.23
	$\delta^{15}N$	11.41	0.15	11.20	0.08	-	-	11.47	0.17	10.77	0.15	9.51	0.19
2009	$\delta^{13}C$	-24.48	0.05	-23.95	0.02	-23.76	0.01	-23.98	0.09	-23.97	0.13	-25.35	0.24
	$\delta^{15}N$	11.37	0.05	11.27	0.06	11.53	0.05	11.26	0.17	11.23	0.24	10.37	0.27
2019	$\delta^{13}C$	-27.67	1.29	-28.47	0.44	-25.19	0.25	-25.38	0.07	-26.08	0.46	-25.98	0.23
	$\delta^{15}N$	15.18	0.50	19.96	0.61	11.32	0.07	10.46	0.06	9.67	0.17	9.84	0.13
2020	$\delta^{13}C$	-	-	-	-	-	-	-	-	-25.93	0.16	10.91	0.13
	$\delta^{15}N$	-	-	-	-	-	-	-	-	-25.34	0.30	11.62	0.19