**FINAL PROJECT REPORT**
**PERFORMANCE PERIOD COVERED:** THROUGH JUNE 2013
**PROJECT TERM:** JULY 1, 2011 – JUNE 30, 2013
**PROJECT TITLE:** Habitat Values of Native SAV (*Stuckenia* spp.) in the Low Salinity Zone of San Francisco Estuary
**REPORT AUTHORS:** Katharyn Boyer, Evyan Borgnis, Jen Miller, Julien Moderan, and Melissa Patten

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***Project Location:*** Suisun Bay and West Delta, San Francisco Estuary

***Brief Description of Project:*** We investigated the potential of native submerged aquatic vegetation (SAV) to provide resources to native fish species in the low salinity zone of the San Francisco Bay-Delta. These SAV beds, composed primarily of *Stuckenia filiformis* (fineleaf pondweed) and *S. pectinata* (sago pondweed), are an extensive feature along many of the islands in Suisun Bay and the west Delta, yet almost nothing was known of their seasonal patterns in physical structure or their invertebrate communities, both of which could influence use by native fishes. We hypothesize that the position of these beds in the shallow subtidal zone along the islands increases resources for fish species, perhaps including species of concern such as delta smelt and chinook salmon. The objectives of this project were to: 1) characterize seasonal patterns in habitat structure of *Stuckenia* beds in four locations in Suisun Bay and the western Delta, with comparisons to four non-native *Egeria densa*-dominated beds), 2) document seasonal changes in the epifaunal invertebrate community composition and abundance in *Stuckenia* versus *Egeria* beds, 3) utilize stable isotope analyses to evaluate

food web relationships within and among the beds, and 4) begin preliminary evaluation of fish use of *Stuckenia* beds through limited sampling inside and outside of beds.

***Primary Objective to be Achieved:*** The primary objective of this project was to evaluate the role of native submerged aquatic vegetation (SAV) beds in providing habitat that may enhance food web support for native fish species in the low salinity zone of the San Francisco Bay-Delta.

## PROJECT STATUS TO DATE (BY TASK)

### TASK 1: MANAGEMENT

Dr. Boyer completed supervision of graduate student assistants and research technicians, as well as undergraduate assistants and volunteers, in field and laboratory data collection, directed invoicing and managed final expenditures on the budget.

### TASK 2: SCIENCE

## METHODS

**Site Selection and Protocol Development.** In summer and fall 2011, we finalized site selection for the project and conducted preliminary sampling to establish field and lab protocols. We trained student assistants and volunteers to assist with plant processing, invertebrate sorting, and stable isotope sample preparation. Dr. Peter Baye worked on identifying the *Stuckenia* species using existing keys and developed a draft key for future use on this and related projects. Dr. Boyer and Ms. Borgnis attended the Coastal and Estuarine Research Federation meeting in Daytona Beach in November 2011 to learn about other brackish SAV sampling conducted elsewhere and to make helpful contacts in support of this project. Both also attended the State of the San Francisco Estuary meeting and discussed potential fish sampling techniques with Dr. Bill Bennett (UC Davis) and also met and discussed the project with Dr. Chris Enright (Delta Science Program).

We selected four submerged aquatic vegetation (SAV) beds in Suisun Bay to represent distributions of native *Stuckenia* spp. and four in the Sacramento-San Joaquin Delta to represent distributions of invasive *Egeria densa.* Beds were chosen to encompass the geographical range of both species from Suisun Bay through the west Delta, and to be dominated by either *Stuckenia* or *Egeria* (although other species could be present and in fact numerous other species were present during the summer in some of the *Egeria* beds; see below). Beds dominated by *Stuckenia* spp. included, from west to east, Ryer, Wheeler, Chipps, and Winter Islands. *Egeria*-dominated beds included, from west to east, Sherman Lake, Decker Island, Big Break, and Fisherman's Cut (Figure 1).

**SAV Species Identification and Mapping.** Through a separate project funded by NOAA Fisheries, we conducted a survey of the extent of *Stuckenia* spp. beds within Suisun Bay and the west Delta during summer of 2011. Beds were mapped using GPS and voucher samples were taken for identification to species. Mapping of the beds was conducted and results submitted in a report to NOAA in mid-February 2012. We developed a web page to make available pdf versions of the maps (http://online.sfsu.edu/~katboyer/Boyer_Lab/Pondweeds!.html) and will provide a copy of the ARC GIS files to the Delta Science Program upon request. Through an augmentation of NOAA funds, we updated the maps in summer 2012 to cover some additional areas and to groundtruth some mapped but unverified locations. We mapped nearly 1200 acres of *Stuckenia* spp. and the areal extent and wide distribution excited the editors of Estuary News, prompting the cover article for the

February 2012 issue, "Submerged Surprise in Suisun" (http://www.sfestuary.org/pages/newsletter.php), which also mentions our Delta Science Program project. Dr. Boyer presented this work at the Bay-Delta Science Conference in October 2012. Our experience in the field during the summer 2011 survey was very useful to narrowing locations to use for our Delta Science Program project (see Site Selection, above). Dr. Peter Baye helped us to determine that there are two native species in the genus *Stuckenia* present within these beds. These include *Stuckenia pectinata* (sago pondweed), as we had expected, but *Stuckenia filiformis* (fineleaf pondweed) may actually be more abundant. Many beds contain both species, and in some cases existing keys do not fully match collected samples or the samples lie intermediate between the species for some features according to the keys. Gross morphology of the plants is very similar and ecological roles are likely to be also, thus we are considering these species as one (*Stuckenia* spp.) for the purposes of this project (with a few exceptions as mentioned below). We continue to collect vouchers when out for other sampling, and especially seek floral/fruiting structures to confirm identification of the plants in some areas. These will help Dr. Baye to complete the draft key he is developing for the *Stuckenia* species in this region of the estuary. In addition, NOAA funds are supporting a common garden experiment in which we are growing *Stuckenia* spp. with different morphologies in the field in tanks over an 18 month period. Results of this study will help us to assess the degree to which environmental conditions determine differences in morphology observed in the field, which will aid in taxonomic verifications. In particular, we are hoping this common garden experiment will highlight features that enable distinction of *Stuckenia filiformis* and *S. pectinata* in the field.

**Sampling Schedule for Plant, Invertebrate and Water Measurements.** Refer to Table 1 for all field dates. During fall 2011, we performed one round of field sampling at two *Stuckenia*-dominated sites, Chipps and Winter Islands, and two *Egeria*-dominated sites, Big Break and Decker Island. This sampling was a preliminary assessment that helped us select appropriate field methods for measuring canopy structure, SAV species composition, invertebrate community composition and abundance, and epiphyte abundance, and for collections of stable isotope samples for food web analyses.

During winter 2012, we measured SAV bed structure by measuring shoot lengths and using the rake method and transect (presence/absence) methods described below. We also collected plant biomass for wet:dry ratios, epiphyte biomass, and invertebrate samples. Samples for stable isotope analysis were not collected this season. Throughout the fall and winter of 2012, we installed one conductivity/temperature continuously-logging sensor within each bed and one temperature-only sensor outside each bed.

During spring 2012, we measured SAV bed structure, plant biomass, epiphyte biomass, and invertebrate community composition. For percent cover at Big Break and Decker Island, only one transect was used instead of three due to limited availability of low tides. We also collected dominant SAV, invertebrates, epiphytes, and algae for stable isotope analysis.

During summer 2012, we measured SAV plant biomass using an additional quadrat method in addition to the standard rake and percent cover methods used on previous sampling dates. For percent cover at Big Break, only one transect was used instead of three due to limitations associated with tides. We also measured invertebrate community composition and epiphyte composition for all sites. Lastly, we collected dominant SAV, invertebrates, epiphytes, and algae for stable isotope analysis.

During fall 2012, we measured SAV bed plant biomass using the rake and percent cover methods as well as shoot lengths. Shoot lengths were not measured at Big Break due to tide levels being too high for measurement. We focused sampling of invertebrate community composition and epiphyte biomass on the four Suisun Bay sites in order to fully characterize them during this season of short daytime low tide windows for field work. Lastly, we collected dominant SAV, invertebrates, epiphytes, and algae for stable isotope analysis.

Table 1. All field dates with sites and activities listed.

| Date | Site | Activity |
|---|---|---|
| 10/24/2011 | Winter Island | SAV biomass, shoot lengths, invertebrates, epiphytes, isotope collections, and installed CT sensor |
| 10/24/2011 | Chipps Island | Shoot lengths, invertebrates, epiphyte, isotope collections, and installed CT sensor |
| 10/26/2011 | Big Break & Decker Island | SAV biomass, shoot lengths, invertebrates, epiphytes, isotope collections, and installed CT sensor |
| 11/04/2011 | Chipps Island | SAV biomass |
| 11/04/2011 | Ryer Island, Wheeler Island, & Sherman Lake | Installed CT sensors |
| 12/13/2011 | Fisherman's Cut | Installed CT sensor |
| 12/13/2011 | All 8 Sites | Installed temperature loggers |
| 2/5 – 2/11/2012 | All 8 Sites | SAV biomass, shoot lengths, epiphytes, and SAV percent cover |
| 2/5 – 2/11/2012 | All Delta sites | Invertebrates |
| 5/6 – 5/20/2012 | All sites except Fisherman's Cut | SAV biomass, shoot lengths, invertebrates, epiphytes, stable isotope collections, and SAV percent cover |
| 6/7/2012 | Fisherman's Cut | SAV biomass, shoot lengths, invertebrates, epiphytes, and SAV percent cover |
| 7/1 -7/03/2012 and 7/19/2012 | All sites | SAV biomass by rake and quadrat, and SAV percent cover |
| 7/30/2012 | All sites | Invertebrates, stable isotope, and epiphyte collection |
| 10/12 – 10/14/12 | All sites | SAV biomass, shoot lengths, SAV percent cover, stable isotope collection |
| 10/12 – 10/14/12 | All 4 Suisun Bay sites | Epiphyte and Invertebrate collection |
| 12/7/12 and 12/19/12 | All sites | Repaired CT and temperature sensor moorings, cleaned sensors and downloaded data |

***SAV Percent Cover.*** We used a transect method to assess SAV percent cover in each bed. This method identifies the upper canopy vegetation community composition and quantifies spatial distribution. Three 50-m long buoyant lines (150 m total) with knots every two meters, were laid out in each bed in a line paralell to shore. At every other 2-m increment, present SAV species were identified and recorded (n = 39). Percent cover was then calculated based on the number of occurrences divided by the 39 possible increments and multiplied by 100. Measuring percent cover with the transect method helps to characterize the entire bed when used in conjunction with the rake method (described below), which characterizes plants growing below the visible canopy. The three percent cover values from each transect were then averaged, providing 3 transect means, which were again averaged for each site for graphing.

***SAV Biomass (Rake).*** We used the rake method described in Kenow (2007) to assess SAV species abundance and collect SAV biomass samples. This method is useful to assess SAV abundance beneath the visible canopy. At three locations (approximately 0-2 m, 24-26 m, and 48-50 m) along each transect, we dragged a long-handled, double-headed thatch rake (head width 33.5 cm, with 18 sharp 13-cm long tines) along the substrate for approximately 1.5 meters. SAV in the rake collections were identified to the species level. Species were then given a percent detection value based on the % of tines filled. The entire plant biomass sample was weighed on the boat using a Balanzza portable luggage scale. Species were then separated and a subsample of each was brought back to the laboratory at the Romberg Tiburon Center. The plant biomass was dried at 60°C for 24 hours and weighed for a wet:dry ratio for each species so that wet biomass in the field could later be converted to dry mass. The three raking scores from each transect were then averaged, providing 3 transect means, which were again averaged for each site.

***SAV Biomass (Quadrat).*** To determine the degree to which the rake method's assesment of SAV biomass within each bed approximates biomass on a per area basis, during the summer 2012 sampling period (when tides were especially low) we collected 3 quadrat biomass samples from randomly selected positions along each transect. At each location, a 0.5 m x 0.5 m quadrat was placed on the substrate by two divers. All of the rooted and floating vegetation within the quadrat's water column was collected by hand. Plant species were separated and each species' biomass was weighed on the boat using a Balanzza portable luggage scale. Three additional quadrat samples were collected within *Stuckenia* spp. patches to assess biomass within patches (not just across patchy beds as is done with the rake method or with random quadrat placement). For these *Stuckenia* patch quadrats, only plants rooted within the quadrat were collected so that shoot densities could be estimated. Samples were taken back to the lab and shoots were counted for a total shoots per area value. Quadrat biomass of *Stuckenia* and *Egeria* was then regressed against the relative proportion (rate 1-5, based on % tines filled) of each species from the raking method following the protocol in Kenow (2007).

***SAV Shoot Lengths.*** At 3 locations (4 m, 24 m, and 48 m) along each of the three transects in each bed, we measured shoot lengths of present species. If any species within the bed were not measured because they were absent from the designated stations, the nearest three shoots of each species to each station were measured. The 3 lengths from each transect were then averaged, providing 3 transect means, which were again averaged for each site. Lengths were measured with the plant manually extended to its full height.

***Epiphyte and Epifaunal Invertebrate Communities.*** At 3 selected points (12 m, 28 m, and 42 m) along each transect (total of 9 points), the top portion of each SAV species was collected to measure epiphyte biomass and for epifaunal invertebrate community identification. In fall 2011, the top 60 cm was measured, cut with scissors, and carefully guided into a 200 micron mesh bag. As invertebrate abundances in the top 60 cm were high, after fall 2011 we decreased the lengths of the plants sampled for invertebrates to 30cm to reduce processing time. After collection, the samples were taken back to the laboratory where the plants were placed in 1L plastic jars. All invertebrates adhering to the mesh bag were washed into the plastic jar as well. A few

milliliters of freshwater was then added and the jar was vigorously shaken for 30 seconds to remove any epiphytic material or invertebrates on the SAV. The water containing epiphytic algae was then placed in weigh boats where the invertebrates were removed with forceps and placed in 70% ethanol in glass vials.
Fresh tap water was then added to the plant sample jar and the process was repeated until the water added to the 1L jar each time was clear of epiphytic algae after shaking. All epiphytic water was dried at 60°C for 24 hours, to remove water from the samples epiphytes. After the plant had been thoroughly rinsed, the plant material was dried at 60°C for 24 hours also, and then the dry biomass was taken.

Invertebrate samples were then enumerated and identified to lowest taxonomic order (species where possible). Confirmations on identification of all observed invertebrates were given by Wayne Fields, a taxonomist at the California Department of Water Resources.

***Stable Isotopes – sample collection and processing.*** At an additional five points within each bed, we collected the top 30 cm of each SAV species using the same field method as the epiphyte and invertebrate samples. Samples were processed using the same epiphyte protocol as described above, except that invertebrates were separated by species, removed from the epiphytic water, allowed to clear their guts for a few hours and rinsed carefully with deionized water to remove any adhering particles before being dried in weigh boats. After drying overnight, all samples (epiphytes, invertebrates, and plant sample) were ground using a mortar and pestle. All equipment used for sample preparation was thoroughly cleaned with methanol and rinsed with deionized water. Composite samples of 3 to 5 individuals were prepared for invertebrates. Samples were then packed in tin capsules: 6-8 mg for plants and epiphytes and 2 mg for invertebrates (based on preliminary analyses and litterature data), to achieve the best possible compromise between C, N and S content and match sample mass requirements for multiple stable isotope analysis (50-500 µg of N, 0.2-5 mg of C and 8-140 mg of S).

***Stable Isotope Analysis.*** Samples were analyzed for C, N and S content and isotopic composition by Continuous-Flow Isotope Ratio Mass Spectrometry (CF-IRMS) at the Center for Stable Isotope Biogeochemistry at the University of California, Berkeley using an IsoPrime 100 mass spectrometer (Isoprime, Cheadle, UK) interfaced with a CHNOS Elemental Analyzer (vario ISOTOPE cube, Elementar, Hanau, Germany). Stable isotope ratios were expressed as parts per mil (‰) in the standard δ notation relative to Vienna PeeDee Belemnite (V-PDB), atmospheric $N_2$, and Vienna Canyon Diablo Troilite (V-CDT) for C, N and S respectively:

$$\delta X(‰) = [(R\ sample / R\ standard)-1] \times 10^3$$

Replicate analyses of international standards (NIST-1577b bovine liver, fishmeal and spirulina) gave long-term analytical errors (expressed as standard deviation) of less than 0.1‰ for C, 0.15‰ for N and 0.4‰ for S. Since S content varied extensively in samples from our study, analytical precision was sometimes slightly lower. The few samples with an estimated error higher than 1‰ for $\delta^{34}S$ were not retained for further analyses.

***Temperature and Salinity Measurements.*** During late October through early November 2011 (Table 1), we deployed one Onset HOBO Conductivity/Temperature logger ("CT sensor"; Model U24-001) at all eight field sites, within the vegetation. In addition, in early December, one Onset HOBO Temperature logger was deployed outside each of the eight beds to provide a comparison to within-bed conditions. Sensors were anchored by twin surplus cinder blocks, attached to surplus stainless steel cable, and suspended by a single yellow "fish float". To prevent biofouling, YSI's "C-spray" was applied to every sensor before deployment. Also, a copper anti-fouling mesh was wrapped around each sensor.

After the first CT sensors were deployed, each was visited during subsequent field days or at least once a month to ascertain stability of the moorings and function of the sensors. Interestingly, biofouling and sedimentation on the sensors varied widely from site to site, ranging from completely sedimented or badly biofouled (and thus prevented from accurate conductivity sensing) to completely clean and in perfect condition. Sedimentation seemed to be a function of exposure to channels and weather, orientation of the sensor, and presence of copper-antibiofouling-mesh. Biofouling differences seemed to follow the expected salinity gradient, west to east, higher salinity to low, bad biofouling to none. We developed a technique to minimize biofouling and sedimentation, thus maximizing potential to collect quality CT data. In the interest of minimizing sensor loss/theft we originally moored each sensor and float a few inches below MLLW; however, turbidity of both Suisun Bay and the Delta was very high, making the recovery of some of the sensors for downloading the data challenging. This resulted in data gaps for some of the field sites between the period of December 2011 – February 2012 or March 2012 – April 2012. We modified the moorings to be visible and above water at most tide stages, resulting in more reliable sensor retrieval. Temperature-only sensors were more difficult to retain, potentially due to their locations in open water, and thus exposed to passing boaters' propellers and curiosity. Unfortunately, during the fall and winter of 2012, several of the CT and many of the temperature loggers went missing. This is likely due to a number of reasons. Firstly, the temperature loggers are in the deeper locations of each site, where they may be swept away by currents. Secondly, the moorings themselves, in particular rope (for initial temperature logger mooring) and stainless steel cable (i.e. not the more robust 316 steel) may degrade or corrode respectively over time. Another reason for such a high percentage of loggers being lost may be theft or boat collisions by other users of this area; for example, one temperature logger was found cut completely in half, which indicated propellor impact.

To reduce the risk of degradation and corrosion of the logger moorings, in December 2012 and January 2013 we replaced all missing loggers and renewed mooring material on all those still present at the sites. These new moorings used 316 stainless steel cable, fed through 3 single stack cinder blocks with the portion in contact with the blocks protected with hosing. 316 stainless steel crosby clamps, nuts, bolts and washers fastened the cable at the surface where it was fed through 2 large fish floats. Each logger was attached to the mooring just below the surface, as before. Galvinizing zinc anodes were also added to the cable near each clamp. These more robust moorings were more successful than the first set, but still some went missing in between sampling efforts. A better way to protect the loggers from theft, collision or drifting would be to attach them to a dolphin or other more permanent structure.

***Light Attenuation Methods.*** Photosynthetically active ratiation (PAR) was measured quarterly within and outside of beds at all 8 sites using a Li-Cor underwater spherical PAR sensor. Measurements were taken in the air (ambient), just below the surface and at 1m depth. We then used the surface and 1m PAR readings to calculate the degree of light attenuation at increasing depths in the water column, within and outside vegetation beds. This indicates the relation of light penetration to SAV types and salinity gradients.

In order to calculate the degree of attenuation, we followed the Bouger-Lambert law which uses the following equation:

$$K(d)=(1/Z_2-Z_1)\ \ln((Ed(Z_1))/(Ed(Z_2)))$$

Where, K(d) = the light attenuation coefficient (higher values indicate less light penetration through the water column), $Z_1$ = depth 1 (surface = 0m), $Z_2$ = depth 2 (1m), $Ed(Z_1)$ = PAR reading at depth 1, $Ed(Z_2)$ = PAR reading at depth 2.

## RESULTS

## PLANTS

***SAV Characteristics.*** In fall 2011, Decker Island had the most abundant SAV and was composed entirely of the invasive species, *Egeria densa*. Big Break showed greater species richness with three SAV species present (invasive *Egeria densa* and *Potamogeton crispus* as well as the native *Ceratophyllum demersum*) at relatively high densities (13-79% detection; Fig. 2). Winter Island also had three SAV species (native *Stuckenia* and *Ceratophyllum* as well as the non-native *Egeria*), but these species occurred at low densities (1-26% detection; Fig. 2). Chipps Island was the most diverse with all four SAV of these species present (Fig. 2).

In winter 2012, we found that many of the SAV species senesced during the cold winter months. This was difficult to observe for some of the sites when only examining percent detection values (Fig. 2), yet it is clear when examining percent cover data from the transect method (Fig. 3) that Wheeler Island lost *Stuckenia* shoots and the western Delta sites had considerably fewer species (Fig. 3). However, Ryer Island, Wheeler Island, and Chipps Island had zero percent cover for all SAV species with small corresponding percent detection values (Fig. 2 & 3). This demonstrates that Ryer, Chipps, and Winter Island *Stuckenia* abundance drastically decreases in the winter season, while Wheeler Island populations completely senesce. As for the western Delta sites, *Egeria* populations survive through winter, but with a great reduction in biomass in the upper canopies as seen by the zero percent cover at Big Break and Fisherman's Cut (Fig. 3). Sherman Lake and Decker Island continued to have dense *Egeria* coverage, but with a complete reduction in other SAV species abundance (Fig. 3). The percent detection values demonstrate that although it may not be visible from the surface, *Egeria* is surviving, rooted in the substrate during the winter. The rake index also demonstrates that there is a reduction in SAV diversity in the winter (Fig. 2).

In spring 2012, all sites had a dramatic increase in SAV species abundace, percent cover, and biomass. Throughout the western Delta, several more species were discovered in the spring season including *Elodea canadensis*, *Myriophyllum spicatum, Stuckenia foliosus, Ruppia* sp. and *Cabomba caroliniana* (Fig. 2 & 3). *Ruppia maritima* was most likely the *Ruppia* species found in the western Delta sites, however taxonomic verfication was not achieved due to missing reproductive structures. Fisherman's Cut and Decker Island continued to have high *E. densa* cover with Sherman Lake and Big Break experiencing an increase in *Stuckenia* abundance in spring (Fig. 2 & 3). Big Break was the most diverse in the spring with seven species of SAV present at relatively low percent detection values. Based on the spring percent cover values (transect method), there was a great increase in cover of *Stuckenia* sp. in the Suisun Bay and an increase in percent cover and species abundance in the western Delta compared to the winter season (Fig. 3).

In summer 2012, all four *Stuckenia*-dominated sites displayed small increases in *Stuckenia* abundances based on the percent detection (Fig. 2). Wheeler and Winter Islands did not have any other species besides *Stuckenia.* Chipps Island had some individual *P. crispus* and *M. spicatum* plants present that did not reside along the transects. For percent cover in summer, sites remained similar to spring with Wheeler, Chipps, and Winter Island increasing in *Stuckenia* cover and Winter Island gaining a low percent cover of *Egeria* (Fig. 3). Throughout the western Delta, two more species were discovered in the summer season including *Potamogeton nodosus* and *Ludwigia peploides* (Fig. 2). Most of the SAV abundances based on percent detection were relatively consistent to the previous season in the Delta, besides Big Break which acquired two new species, *Potamogeton nodosus* and *Ruppia* sp. For percent cover (transect method) during the summer there were no new species additions in the Delta's surface waters; however, there were decreases in certain species. Big Break contained less *Elodea, Ceratophyllum,* and *Cladophora* and there was a complete loss of

*Ruppia* sp. (0% in summer; Fig. 3). *Cladophora* also decreased at Sherman Lake during the summer. Decker Island continued to have 100% cover of *Egeria* throughout the summer.

In fall 2012, only *Stuckenia* was detected at all Suisun Bay sites, excluding Ryer Island where <1% *C. demersum* and *E. densa* were detected in addition to *Stuckenia* (Fig. 2). Based on percent cover, only *Stuckenia* was found at all Suisun Bay sites (Fig. 3). Fall was a productive season with high *Stuckenia* detection and percent cover values, with Chipps Island exhibiting the lowest *Stuckenia* cover. Chipps Island *Stuckenia* beds grow in round, clonal patches. In fall 2012, these patches appeared to be more widely spaced apart. Considering that rake and transact locations were placed in relatively the same locations each sampling period, neither method captured the true abundance of *Stuckenia* at Chipps Island as its distribution had shifted. Wheeler Island *Stuckenia* abundance steadily increased throughout the season with its peak (based on both methods) in fall. In the Delta, SAV distributions were relatively similar to summer. Sherman Lake returned to being dominated by *E. densa* based on detection and percent cover (Fig. 2 & 3). Fisherman's Cut's floating vegetation distribution increased with *L. peploides* covering 77% of transect area and *H. verticillata* covering 28%. The harmful alga, *Microcystis aeruginosa* became present with a large percent cover value of 92% across the water surface (Fig. 3). Based on percent detection, Fisherman's Cut remained dominated by *Egeria* with *C. demersum* increasing its establishment at the site. Although Decker Island remained completely dominated by *Egeria* in the fall, as in all other seasons, *C. demersum* established with a low percent cover value of 10% (Fig. 3).

*Stuckenia* shoot lengths were relatively consistent throughout the seasons within each site, with the lowest lengths during the winter, if any plants were present (Fig. 4). In winter, most *Stuckenia*-dominated sites did not have plants along the transects; therefore, no data were collected on lengths at Ryer, Wheeler, or Chipps Islands. Winter Island plants along transects had an average shoot length of 160 cm (Fig. 4), much shorter than the average length for all other seasons at Winter Island (~229 cm). Sherman Lake had consistently lower shoot lengths for *Stuckenia* with a range of 130-167 cm throughout seasons and no *Stuckenia* during the winter. Chipps Island *Stuckenia* lengths were consistent throughout seasons with a range of 205-255 cm. Although we combined *Stuckenia* species in this analysis because we could not distinguish them with certainty, based on morphology, Chipps Island plants keying most closesly to *Stuckenia pectinata* were shorter (122 cm) than plants presumed to be *Stuckenia filiformis* in summer. As for *Egeria,* shoot lengths were shorter or there was no *Egeria* present in the winter season compared to all other seasons. However, this was not the case for Decker Island (Fig. 4), which had consistent shoot lengths throughout the seasons, with a winter peak of 159 cm. Sherman Lake had shorter plants than the other seven sites for *Stuckenia, Egeria, Stuckenia foliosus* and *Potamogeton crispus*. *Ceratophyllum* had consistent shoot lengths between all sites and seasons, except winter when it was not found at any site. *Myriophyllum* was only found at Big Break and Fisherman's Cut in the spring and summer and was longest at Fisherman's Cut (Fig. 4).

In the summer, we collected large SAV biomass samples using quadrats to confirm the accuracy of using the rake method for biomass collections. When comparing the methods for *Stuckenia* sp., the rake method was not found to be a good predictor of biomass (regression $p = 0.252$; $R^2 = 0.10$, Fig. 5 left). This could be due to the low number of samples, suggesting that more quadrat collections are needed for this analysis. However, after comparing the methods for *Egeria densa* it seems the rake method is a much more accurate predictor of biomass than for *Stuckenia* (regression $p = 0.001$; $R^2 = 0.63$, Fig. 5 right). In terms of the biomass data, Ryer Island had the highest biomass of *Stuckenia* and Decker Island contained the highest biomass of *Egeria* as seen in our raking method (Table 2). Sherman Lake contained a relatively even amount of biomass for both *Stuckenia* and *Egeria.*

Table 2. Average biomass of *Stuckenia* sp. and *Egeria densa* collected using the quadrat method for all sites (n=3).

| Site | Species | Ave Biomass (kg/m$^2$) | SE |
|---|---|---|---|
| Ryer Island | *Stuckenia* sp. | 3.4 | 1.00 |
| Wheeler Island | *Stuckenia* sp. | 1.3 | 4.40 |
| Chipps Island | *Stuckenia* sp. | 2.5 | 0.70 |
| Winter Island | *Stuckenia* sp. | 1.0 | 0.21 |
| Sherman Lake | *Stuckenia* sp. | 1.1 | 0.36 |
| Sherman Lake | *Egeria densa* | 1.1 | 0.45 |
| Decker Island | *Egeria densa* | 4.3 | 0.92 |
| Big Break | *Egeria densa* | 0.9 | 0.23 |
| Fisherman's Cut | *Egeria densa* | 2.7 | 0.48 |

***Epiphyte Loads.*** In fall 2011, Big Break had the highest diversity of SAV species, which also corresponded with highest epiphyte biomass values. At Big Break, *Ceratophyllum demersum* had the highest epiphyte biomass with an average 56% of epiphytic biomass per dry *C. demersum* biomass. All sites' SAV species samples contained epiphytic material in the fall sampling season, with Chipps Island *Stuckenia* having the least amount of epiphyte biomass (Fig. 6). In winter 2012, many sites did not have SAV present, and only sites with *Egeria densa* had epiphytes. Once again, SAV samples from Big Break contained the highest percent epiphytic biomass at 40.7% of total dry biomass. Although only *E. densa* was present at Decker Island, plants at this site did not have measurable epiphytes (Fig. 6). In spring 2012, we did not collect a full set of samples for epiphytes and only Chipps Island, Fisherman's Cut, and Decker Island had usable epiphyte data. Although the dataset included only these three sites, it is clear that epiphytic biomass still had not recovered from the winter decline with low values ranging from 14-18% of total dry biomass (Fig. 6). In the summer, most of the epiphytes had re-established at the eight sites. *Stuckenia* epiphyte loads were relatively consistent throughout the sites, but with somewhat lower epiphyte biomass at Ryer and Winter Islands. *Myriophyllum spicatum* had high epiphytic biomass at Chipps and Sherman Island. The most diverse SAV beds tended to have the highest epiphyte biomass and the highest amount of variation (Fig. 6). In fall 2012, we focused sampling solely on the Suisun Bay sites due to time constraints of limited low tide windows. The two Suisun Bay sites that were sampled the previous year in fall 2011, Chipps and Winter Islands, decreased in epiphyte biomass from 2011 to 2012. Chipps decreased by 75% and Winter Island by 62%. However, all Suisun sites were relatively similar in epiphyte biomass as the previous season, summer 2012.

## EPIFAUNAL INVERTEBRATES

***Graphical and Data Analysis Methods:*** To investigate species diversity, a Shannon diversity index was calculated for both regions (Delta and Suisun), and then each site and season, in relation to the mean invertebrate abundances using the R package "vegan" (Oksanen, J. et. Al., 2013). Mean abundances were calculated per sample (i.e. per 60cm of the SAV sample collected).To investigate the community structure of invertebrates associated with the SAV beds, we carried out a Correspondence Analysis (CoA) in the R package "ade4" (Dray, S. and Dufour, A.B., 2007). It is important to note that due to field work intensity, fluctuations in SAV sample availability, and natural fluctuation of invertebrate abundance, the sampling strategy was inevitably slightly unbalanced and this can cause a relatively high variation in the abundance

data, especially between seasons and sites. When a CoA was run on a smaller subset database comparing just spring and summer, and then fall and winter, however, the CoA output showed the same patterns as those based on the whole database. Also, we initially collected the top 60cm of each plant, and then decided to collect 30cm from winter (February) 2012 onwards and so the fall 2011 invertebrate abundances were halved prior to graphical representation, analysis and calculation of the mean values.

***Seasonal Abundance Overview.*** Table 1 in Appendix I shows the mean abundance of each invertebrate taxon by site and season. In fall 2011, the most common taxa in Suisun Bay sites were the amphipod *Gammarus daiberi* and *Chironomus* sp. (midge fly larvae). In addition, the most common species in the western Delta were the amphipod *Hyalella azteca* and the same midge fly larvae.

In winter 2012, all Suisun Bay sites, except Winter Island, did not have invertebrates present on SAV collected, mainly because nearly all of the SAV had senesced. On the other hand, Winter Island and all of the western Delta sites had invertebrates present, mainly on *E. densa.* In winter 2012, the invertebrate communities were dominated by *Physa* sp. in the Delta.

In spring 2012 the most common invertebrates in Suisun Bay and the western Delta were the isopod *G. oregonensis* and the gastropod *Physa* sp. respectively. There were very few invertebrates in the Suisun Bay SAV samples collected in spring 2012.

In summer 2012, the most common invertebrates in Suisun Bay were the midge fly larvae, and the same isopod, *Gnorimosphaeroma oregonensis.* In the Delta, however, the most common invertebrate was again *Physa* sp.

The highest abundance of invertebrates was seen in the Fall 2012 samples. We did not collect fall 2012 samples from the Delta sites, but in Suisun Bay the most common invertebrate species was *G. daiberi* again. Additionally, the second most common invertebrate species in Suisun Bay was the invasive invertebrate *Amphithoe valida* at Ryer Island and Wheeler. *A. valida* is generally only found in more saline environments so this was a surprising addition to the invertebrate community. That said, the fall months after a dry summer permit higher salinities in the estuary which would enable *A. valida* to migrate east into normally fresher sites.

***Abundance by Taxonomic Group.*** In order to display the mean abundances of the invertebrate species found, we have combined the species into 5 higher level taxonomic groups. 1. Amphipods (*Gammarus daiberi, Hyalella azteca, Americorophium spinicorne,* and *Ampithoe valida*); 2. Isopods (*Gnorimosphaeroma oregonensis, Caecidotea, Synidotea laticauda*)*; 3.* Gastropods (*Physa* sp.*, Helisoma anceps, Hydrobia* sp.*, Fluminicola* sp.*, Gyraulus circumstriatus);* 4. Insect Larvae (Midge-fly larvae and pupa and Dragon-fly larvae); 5. “Other” (Hydrachnidae*, Schmidtea* sp.*, Palaemon macrodactylus* and *Pancolus californiensis*).

Overall, for the entire 2012 sampling period there is great variation in the mean abundance of invertebrates at the different sites (Fig. 7). In Suisun Bay, amphipods dominated the invertebrate community in abundance, with Wheeler showing the greatest overall mean abundance. Isopods seem to be the next most abundant group in Suisun Bay, and this group was most abundant at Chipps Island. Insect larvae were only present at Winter Island in Suisun Bay. Overall, Ryer Island and Chipps Island had a lower mean invertebrate abundance than Winter or Wheeler.

At the fresher Delta sites, gastropod species contributed the most to the overall average abundance, followed by amphipods and then isopods. Of the Delta sites, Big Break has the highest mean abundance of

invertebrates, closely followed by Decker Island and Fisherman's Cut. Sherman Lake had the lowest mean abundance of invertebrates of the Delta sites across seasons. This may be due to its more central location within smaller channels, with intermediate salinity fluctuations preventing those invertebrates that are highly adapted to higher or lower salinities from inhabiting this area. Additionally, Sherman Lake had a fairly equal proportion of different invertebrate taxa, perhaps reflecting its midpoint location. Insect larvae were present at all four of the Delta sites, but not in high abundances in Suisun Bay.

There was high variation in community composition and abundance at the 8 sites between fall 2011 to winter 2012, with a maintained community dominance by amphipods in the Suisun Bay and gastropods in the Delta (Fig. 8a-e). The overall pattern of invertebrate abundances was highly variable between seasons and sites.

Overall, Suisun Bay sites showed lower abundance of invertebrate groups throughout the year, but a large increase in abundance in both the fall sampling periods explain the overall high mean abundance across all seasons. There was a drop in the mean abundance of invertebrates from fall to spring and a gradual increase to summer 2012, likely explained by the regrowth of the SAV after the winter senescence. There was also a surprising switch from Fisherman's Cut showing the highest abundance in spring, and Big Break then showing the highest abundance in summer. Insect larvae populations appeared to be at their peak in fall (judging by their abundance in fall 2011) in the Delta sites, but still in fall the gastropods dominated the overall abundances in those sites. In Suisun Bay amphipods dominated the invertebrate assemblages, particularly at Wheeler and Winter, and made up most of the high fall abundances. It seems that gastropods are the main invertebrate community constituents in winter 2012 in the western Delta when nearly all the SAV in the Suisun Bay has sensesced.

***Invertebrate Species Diversity*.** The invertebrate assemblages appear to follow a rather classic pattern of diversity in estuarine ecosystems (see Remane, 1934 and Whitfield et al., 2012 and references therein) with higher diversity in the freshwater part of the system (upstream sites), and lower diversity in the oligo/mesohaline areas (downstream sites) (Fig. 9). Summer 2012 had the highest diversity index, but it is important to note that the fall 2012 collections did not include the Delta sites, and so this index value would likely be lower than if the Delta sites were incorporated. Wheeler in the Suisun Bay had a relatively high diversity of invertebrate species, and also showed higher overall abundance of invertebrates on average in 2012 (Fig.7), perhaps indicating that this SAV bed is particularly high quality habitat for those invertebrates, and particularly amphipods. The highest invertebrate species diversity was seen at Decker in the western Delta, with Fisherman's Cut having a slightly lower diversity index. Both sites showed high SAV diversity later in the year, which would encourage more invertebrate diversity if the invertebrate community consists of species preferring specific plant species over others. Higher invertebrate diversity in the Delta could be explained either by higher plant diveristy in this region, or simply by more constant environmental conditions (freshwater almost all year round) allowing less tolerant and robust invertebrates to live in those waters compared to the more variable and thus harsher conditions in Suisun Bay.

***Invertebrate Community Variability***. In order to investigate the similarity of invertebrates in different samples in relation to their environmental variable, we carried out a Correspodence Analysis (CoA, Fig. 10) . This CoA first distributes the samples (as numbers) indicating the overall spread of variability (similarities and differences) of our samples along the 1$^{st}$ (horizontal) and second (vertical) axes of the CoA (Fig.10.A). There is a clear curve (Guttman or "horseshoe" effect) indicating that a strong environmental gradient is directing the spread of our samples and thus supporting a succession of species: samples in the lower left and lower right parts of the biplot, despite appearing relatively close to each other, are actually found on the opposite ends of that underlying gradient and have little or no species in common. Looking now at the ordination of species (Fig.10.B), they appear to be divided into two main groups along the horizontal axis, with invertebrates found in

the Delta on the left, and those found in Suisun Bay on the right. The group on the right seems more spread along the vertical axis, suggesting that these species form a less homogeneous brackish water community compared to the fresher Delta. The more distance between invertebrate species indicates they are infrequently found in the same samples.

This first axis explains 16.4% of the variability, emphasizing the importance of our primary environmental variable on the invertebrate community: most likely the salinity gradient. The two other axes are mostly related to the intra-region (i.e. within the Delta and Suisun) variation, due to a mix of spatial and seasonal effects. Axis 2 and 3 account for 13.3% and 12.5% of the species abundance variability, respectively. Overall, the three axes of the CoA explain 42.2% of the variability of our invertebrate species communities.

To investigate the potential drivers responsible for that SAV invertebrate community structure, samples were then highlighted subsequently as a function of sites, SAV species and season by replacing the sample labels with colored dots and adding ellipses with axes length = 1.5×eigenvalue from the covariance matrix to summarize the dots' cloud for each group (Fig. 10 C, D and E).

It is clear that there is some overlap of species present at the four Delta and four Suisun sites (Fig.10.C.), which is likely due to the seasonal fluctuations in salinity allowing invertebrates generally found in freshwater Delta sites to colonize the upper Suisun sites in the winter and spring (during and after rainy months) and invertebrates generally preferring slightly higher salinities (and more tolerant to short term salinity variations) to colonize the lower Delta sites in the summer and fall (during dry months). One example of this is seen in the isopod *G. oregonensis* that was found mainly in the Suisun sites but was detected in the Delta during the late summer and fall 2012 sampling efforts.

There does not seem to be a distinct pattern between the SAV species and invertebrate species, other than STFI (*Stuckenia filiformis)* mostly matching the oligo-mesohaline (Suisun Sites) invertebrate species coordinates, but logically hosting freshwater species assemblages when sometimes found in the Delta (Fig. 10.D). It is clear as well that the Delta and Suisun samples' opposition along the first axis also reflects the plant diversity at those sites, with the Delta sites hosting much more diverse plant communities (including numerous non-native species) while generally only *Stuckenia* spp. were found in Suisun.

Finally, when looking at the seasonal patterns there is a clear story. In the winter, as aforementioned, the plants in Suisun Bay senesce and there are very few invertebrates remaining. Plants in the Delta sites remain (although in lower densities) throughout the winter by contrast, allowing a more consistent community of invertebrates. This explains the clear separation of the invertebrate samples in winter 2012 (Fig.10.E). The spring samples from the Suisun had very few invertebrates, presumably due to their habitat slowly regrowing after the winter senescence whereas the Delta plants are recovering from a higher initial population. This explains the clear overlap of spring and summer invertebrate communities – where the Delta samples constitute the overall invertebrate community. However by fall, the plants in Suisun Bay have rapidly grown and a subsequent population bloom of invertebrates occurs in those sites, giving the highest invertebrate abundances of the year and showing a very clear and large spread of fall samples. The larger plant sample lengths collected in fall 2011 may cause the invertebrate abundances to be higher in that season relative to the other seasons which may accentuate the separation of seasonal patterns, especially fall (=fall 2011 and 2012 combined) vs. the other three seasons. However, when we ran a CoA on just the 2012 seasons, the pattern was not different, and the same seasonal distinctions were clear.

## ELEMENTAL AND ISOTOPIC ANALYSIS RESULTS

***Graphical and Statistical Analyses.*** Epiphytes, algae, invertebrates, SAV, and floating aquatic vegetation (FAV) were collected in fall 2011 and spring, summer and fall 2012 for elemental and stable isotope analysis. Only the four *Stuckenia*-dominated sites (Ryer, Wheeler, Chipps and Winter) were sampled in fall 2012 as mentioned previously. The most comprehensive data set (including a sufficient number of invertebrate samples) is from these four Suisun sites in fall 2012, on which we thus focus the foodweb part of our analysis.

Data were analyzed and plots created with the R software (R development Core Team, 2013). Since we were more interested by the source and range of variation in the data rather than "point" values, boxplots were used as a powerful way to summarize the information through quartiles (Fig. 11): a box is drawn around the median from the lower hinge (Q1) to the upper hinge (Q3), with "whiskers" extending to the most extreme data point that is no less than Q1-1.5×IQR (Inter-Quartile Range), or not greater than Q3+1.5×IQR. Data points outside of this range are depicted as outliers (dots).

For individual response variables (e.g. %C), differences among sites, season or sample type (e.g. plant species) were investigated using 1-way or 2-way ANOVAs and Tukey's HSD posthoc tests when assumptions for the use of parametric procedures were met (normality and homoscedasticity, checked using linear model diagnostic plots). Otherwise, we used Kruskal-Wallis tests, followed by non-parametric multiple comparisons procedures.

Responses of groups of dependent variables (e.g., all elemental and isotopic variables) to 1 or 2 independent variables (site, season, sample type) were explored using permutational multivariate analysis of variance (PERMANOVA).

Wilcoxon signed-rank tests and Mann-Whitney U-tests tested for differences between *Stuckenia filiformis* and *Stuckenia pectinata*, when taking into account paired samples or all available samples, respectively.
A Principal Component Analysis (PCA) allowed us to explore patterns of variability in the elemental and isotopic composition of all the plants samples collected.

We used Bayesian Stable Isotope Mixing Models (SIAR, Parnell & Jackson, 2013) to evaluate likely percentage contributions of different organic matter sources to the diet of the main invertebrate consumers. SIAR uses stable isotope data from the consumers and the sources, along with trophic enrichment factors (TEF), to fit a Bayesian model to the consumers' dietary habits based upon a Gaussian likelihood with a dirichlet prior mixture on the mean. Bayesian mixing models offer the advantage of explicitely accounting for uncertainty from diverse sources as the user can specify that uncertainty for both sources and consumer data, and TEFs (e.g. standard deviation).

***Plants.*** For each of the variables considered, significant differences among plant taxa were detected (1-way ANOVA, $p<0.001$ for all variables except $\delta^{15}N$ $p<0.01$; Fig. 12). Epiphytes had C contents 2 to 10 times lower than any other plant taxa (3 to 21%C as compared to ≃ 35%C), although *Cladophora* and *Stuckenia* displayed large variations across sites and season (from ≃20 to >40%C). Epiphytes also had low N content (from <1 to 3%) and low C/N ratios (≃4 to 8) as compared to all other plant taxa (2 to 6%N), which could be at least partly due to contamination of the samples by non organic material (sediment). *Cladophora* displayed rather high N and C content (up to >6 and >2%, respectively), which translated into low C/N ratios (5 to 8). C/N ratios in *Elodea canadensis* were notably more variable than in any other species, reaching values as high as almost 20.

*C. caroliniana* was significantly $^{13}$C-depleted as compared to all other plant taxa, reaching $\delta^{13}$C values as low as –35‰ (Fig. 12). *E. densa* was also slightly $^{13}$C-depleted (to -28‰), particularly when compared to *Stuckenia* spp. (>-15 to -22‰). Differences in $\delta^{15}$N values were less pronounced, with only *C. demersum* being significantly 15N-enriched as compared to *E. canadensis*. At the annual scale and without considering sampling location, significant differences in $\delta^{34}$S values were only detected between *Cladophora* or *Stuckenia* spp. and the other taxa. Both of them were often significantly enriched in $^{34}$S. Most of these plant taxa for which we were able to collect enough samples to cover different seasons and sampling sites displayed rather large range of variations in their stable isotope composition (up to 10‰ for C and N, and >25‰ for S in epiphytes), reflecting either changes in their primary nutrient sources or more probably high spatio-temporal variations of the stable isotope composition of these sources in relation with freshwater flow (C and S). This emphasizes the need for thorough documentation of the spatio-temporal variability of the sources of organic matter at the base of the food web when applying stable isotope analysis to ecosystems as dynamic as estuaries. It also justifies the need to focus the foodweb part of our study on selected sites and seasons.

We also tried to compare two species of *Stuckenia* (*filiformis* and *pectinata*) but were limited by the number of samples that we presumed to be *S. pectinata* (Fig. 13). While significant differences in $\delta^{15}$N were detected when taking into account all the available samples (Wilcoxon test for independent samples, $p<0.001$), these differences appeared marginally non-significant when comparing samples from both species collected at the same time and location (Wilcoxon test for paired samples, $p=0.07$, Fig. 13). More samples will be needed to allow testing with higher statistical power and to eventually confirm that *S. pectinata* might be slighlty 15N- and 13C-depleted as compared to *S. filiformis*.

We then decided to focus our analysis on the 3 most commonly found plant taxa (*Egeria densa*, epiphytes and *Stuckenia* spp.) to investigate spatial differences within each of the 4 sampling seasons (Fig. 14 to 17). Each time, a significant interaction between sampling site and taxa was detected (PERMANOVA, $p<0.01$), highlighting overall large interspecific and spatial variations in the elemental and isotopic composition of these plants. *Stuckenia* spp. displayed increasing C/N ratios from downstream to upstream in fall 2011 and summer 2012, while they tended to decrease in spring 2012. Although the N content of *Egeria densa* appeared quite variable in fall 2011 (its C/N ratios showing logically opposite variations), this was not the case in spring, summer and fall 2012 for which we generally were able to collect more samples. In fall 2011, no clear spatial pattern in the C and N stable isotope composition of these plants could be observed, while their $\delta^{34}$S values were generally sharply decreasing from the downstream Suisun sites to the upstream Delta sites (except in that case for *Stuckenia* spp. for which the spatial coverage apeared too limited in fall 2011 to accurately detect any pattern). This clear trend toward $^{34}$S-depleted plant tissues in freshwater was observed for most species and all seasons (Fig. 15 to 17), confirming that plants synthesize organic S from inorganic sulphate with no or little isotopic fractionation and thus mirror the $\delta^{34}$S values of ambient sulphate (Trust and Fry, 1992). Since sulphate in freshwater typically has very low or even negative $\delta^{34}$S values while marine water sulphates have high (>20‰) $\delta^{34}$S values, a sharp drop in $\delta^{34}$S for plants samples collected across the low salinity and freshwater area of the estuary is not surprising. A drop of almost 15-20‰ in sulfate-$\delta^{34}$S within a few salinity units is a common feature of estuarine ecosystems as documented, for instance, by Fry and Chumchal (2011) for Louisiana estuaries.

This spatio-seasonal analysis also confirmed that *Egeria densa*, with $\delta^{13}$C values ranging from -20 to < -25‰, was slightly more $^{13}$C-depleted than *Stuckenia* spp. and epiphytes whose $\delta^{13}$C values were most of the time around -20‰ in fall 2011 and spring 2012 and up to -15‰ in summer 2012.

It is interesting to note in spring 2012 the clear decreasing trend in *Egeria densa* $\delta^{15}$N values from about 15‰ upsteam (Fisherman's Cut in the San Joaquin river) down to 5‰ at Winter Island (Fig. 15). A similar although

less pronounced pattern is seen in the epiphyte N isotopic composition. Those low $\delta^{15}N$ values appeared rather exceptional and were not observed during any of the other seasons. They were probably due to winter/early spring higher precipitation and freshwater flow that led to a clear gradient in the stable isotope composition of the N-nutrients used by these plants: from $^{15}N$-enriched close to the potential sources in freshwater (probably under more direct influence of the waste water treatment plants up in the river) to lower $\delta^{15}N$ values downstream. During fall and summer, lower freshwater flow and higher residence times likely resulted in more intense bacterial processing of organic matter and recycling of these nutrients within the Delta and low salinity zone, homogeneizing the stable isotope signature of the ambient nutrient pool and stabilizing the plants $\delta^{15}N$ values around 12‰. *Egeria* seems thus to respond more efficiently and quickly to changes in the sources of nutrients and could be a better indicator for acute and short events of anthropogenic N inputs to the system (sewage water, fertilizers…) for monitoring purposes. It probably has higher growth rates than epiphytes or *Stuckenia* spp. whose isotopic turnover rates would thus be too low for them to reflect rapid changes in the nutrient stable isotope composition. Instead, *Stuckenia* and epiphytes seemed to have a rather high intra-site variability in spring 2012 (Fig. 15), probably reflecting differences between “old “ and freshly produced tissues/samples.

A closer look at *Stuckenia* spp. spatio-seasonal variations in isotopic and elemental composition (Fig. 18) shows some increasing trends from downstream to upstream in their C content and C/N ratio in summer 2012. This pattern appeared reversed in spring 2012, during which N was slightly higher and increasing toward the freshwater end-member, leading to comparatively low C/N ratios. When we were able to find *Stuckenia* spp. in the upstream part of the system (Delta/*Egeria*-dominated sites in spring and summer 2012), their S stable isotope composition followed the same sharp transition toward highly $^{34}S$-depleted samples in freshwater that we previously described. Any attempt to use S isotopes to infer the diet of estuarine primary consumers in the low salinity / freshwater transition area should be imperatively based on consumers and plants samples collected at the same time and place. As previously hypothesized, the large intra-site variations in *Stuckenia* $\delta^{15}N$ values in spring 2012 (2 to 3 times larger than usual at RI, WH and CI) are probably a consequence of underlying variability in the stable isotope composition of the available N-nutrient source.

The first 2 components of the PCA we conducted on the elemental and isotopic variables for the full dataset explained, respectively, 29.8 and 24.8% of the total variance, while the third axis explained another 19.4% (Figure 19 and 20). The first axis was almost exclusively negatively related to the C content and the C/N ratio, which thus displayed logically strong correlations with one another. The second axis was positively related to $\delta^{13}C$ and $\delta^{34}S$ and negatively related to the percentage of N. The third component was negatively related to the percentage of S and $\delta^{34}S$. $\delta^{15}N$ was never related to any of the meaningful components of the PCA. This PCA did not produce a clear-cut separation of our samples based on either sampling season or sampling site, confirming the results of the overall PERMANOVA. The effect of each of these main independent variables was always lower than the interaction between them. This translated into high intra-class (high dispersion of our samples for a same season or site) and low-inter class variability in the PCA. Nevertheless, epiphytes were clearly separated from all of the other taxa along the first axis due to their extremely low C content and C/N ratio, and *Cladophora* samples were isolated on the negative part of the third component, reflecting their high S content and $\delta^{34}S$ values.

***Invertebrate Consumers (Fall 2012: Suisun sites).*** Except for $\delta^{15}N$ (which is known to be poorly discriminant regarding the organic matter sources at the base of the food web and should not be really different for consumers feeding at the same trophic level), all of the elemental and isotopic variables differed significantly between the 3 invertebrate species (Kruskal-Wallis, $p<0.001$ for %N, C/N and $\delta^{34}S$; $p<0.01$ for %C, %S and $\delta^{13}C$; Fig. 21). *G. daiberi* had higher C and N content than *G. oregonensis, A. valida* had overall lower S content than *G. daiberi*, and *G. oregonensis* had a significantly higher C/N ratio than both other species.

Overall, *G. daiberi* seemed to have slighlty lower $\delta^{13}C$ values than the 2 other species (although this was not always true when considering samples collected at the same site), and *G. oregonensis* was always $^{34}S$-enriched as compared to *G. daiberi* and *A. valida*. Within a species, spatial variations appeared more pronouced in $\delta^{13}C$ (Ryer Island always had less negative values than most of the other sites) than in $\delta^{34}S$ or $\delta^{15}N$ (although for instance *G. oregonensis* displayed rather high inter-individual variability in N isotopic composition at Ryer Island). There also seemed to be a gradient in the C and N content of *G. oregonensis* from low % at the most downstream sites to higher % upstream.

Dual isotopes plots (Fig. 22) and Bayesian stable isotope mixing models (Fig. 23 to 26) were then used to identify the sources of organic matter most likely to contribute to the diet of the most abundant invertebrate consumers, and to investigate trophic relationship among these 3 species at the 4 Suisun sites. While Cladophora, epiphytes and Stuckenia spp. were collected and analyzed at each of these sites, particulate organic matter (POM) and benthic diatoms signatures were obtained from other projects and were thus the same for all of the sites. POM samples (Moderan, pers. com., 2013) were collected at the same period (fall 2012) by filtration of a know volume of local water on pre-combusted GF/F glass fiber filters, dried and acidified to remove carbonates before analysis. Additional information about these samples (C/N and C/chloropyll a ratios mainly) indicated that although not exactly representative of pure phytoplankton, they were phytoplankto-rich and were thus a good proxy for this source. Benthic diatom data were obtained from the literature available on the same general area of the San Francisco Estuary (Howe et al., 2011). We applied a trophic enrichment factor (TEF) of 0.5 for C, 2.2 for N and -0.5 for S, typically reported for aquatic primary consumers feeding on low protein or vascular plant organic matter sources (McCutchan et al., 2003).

At RI and WH, *A. valida* seemed to display some isotopic and probably trophic overlap with *G. oregonensis* and *G. daiberi,* respectively (Fig. 22). Although not necessarily distant from each other in the stable isotope space, the different consumers were otherwise occupying slighlty different “isotopic” niches, indicating that they certainly shared some of the available ressources but were not always using them in the same proportion.

At RI, in the absence of *Cladophora*, both *A. valida* and *G. oregonensis* appeared to have a diet clearly dominated by *Stuckenia* spp., whose contribution could range anywhere from 60 (*A. valida*) or 40% (*G. oregonensis*) to 100% (Fig. 22 & 23). The remaining part of the diet is probably composed mainly of epiphytes.

At WH, all 3 species were present, but while *A. valida* and *G. daiberi* seemed to feed mainly on *Cladophora* (and probably on epiphytes to a lower extent), *G. oregonensis* samples were outside of the mixing polygon connecting the 5 available sources, preventing the model from accurately estimating their diet (Fig. 22 & 24). *G. oregonensis* might thus have been specializing at WH on an undocumented source of organic matter or could have switched to a partly carnivorous diet composed of organisms feeding on epiphytes and *Stuckenia* spp. (meiofauna?).

An interesting feature of CI was the high contribution of POM (or of terrestrial $C_3$ plant detritus from the watershed whose stable isotope signature would probably be in the same range) to the diet of *G. daiberi*: 40 to 60%, mainly complemented by *Cladophora* (20 to 50%) and no or little contribution of *Stuckenia* and epiphytes (Fig. 22 & 25). The same pattern was observed in *G. oregonensis* at that site although the contribution of the highly $^{13}C$-depleted sources (POM) was apparently lower (20 to 40%). It was harder, if not impossible, to identify which of the other available OM sources contributed to its diet: all of them could have contributed anywhere from 0 to 30 or 40%, but they were also strongly negatively correlated with each other, meaning that if *Stuckenia* for instance had a high contribution, epiphytes that had a rather similar signature at this site would necessarily have contributed less.

Finally, at WI, although uncertainties were high regarding the relative contributions of the different organic matter sources of the diet of the invertebrates, both *Cladophora* and epiphytes were certainly consumed, with a likely additional contribution of POM for some *G. daiberi* individuals (one is clearly 13C-depleted as compared to the other ones), and *Stuckenia* for *G. oregonensis*. Benthic diatoms never appeared to contribute to the diet of any of these invertebrate species (Fig. 22 & 26).

## FISH

***Preliminary Fish Sampling***. Dr. Boyer assisted graduate student Teejay O'Rear (Peter Moyle's laboratory at UC Davis) with regularly-scheduled fish sampling in the sloughs within Suisun Marsh (Montezuma Slough and Nurse Slough) on August 26, 2011, with the objective of exploring fish sampling options for *Stuckenia* beds. We deployed a total of eight minnow traps and eight clover traps (all baited with wet cat food), four of each inside and four of each outside a *Stuckenia* spp. bed. For each set of four traps, two were buoyed to float near the surface and the other two weighted to rest at the bottom. After ~4 hours on a flood tide we returned and examined the traps. We caught very few fish with these traps; we found only a few tule perch (67-69 mm length) in one of the bottom-resting clover traps. Mr. O'Rear tried deploying these same trap types again on October 17, 2011 and left them out throughout an entire ebb tide. Again, very few fish were caught. As a comparison, trawling across a *Stuckenia* patch on the same day caught dozens of fish (mostly young of the year tule perch). We are not pursuing trawling for future fish sampling in *Stuckenia* beds due to damage to the plants, but this one attempt demonstrated that fish are using the beds, and that, in contrast, traps are not effective at capturing fish in these beds. A conversation with Dr. Bill Bennett (also UC Davis) led to the suggestion of using a purse seine or pop net of some sort that could be used to trap fish and then be worked up gently through the water column to remove the vegetation. Without funding in our project to pursue these ideas further, we are hopeful that these initial investigations can be developed into a project for assessing fish use of *Stuckenia* beds through a future funding opportunity.

## WATER QUALITY

***Salinity*.** In February 2012, all Delta sites remained fresh with increasing salinities moving westward (Fig. 27). Suisun Bay sites were the most fresh in the winter (Feb) with a peak of 3.0 ppt at Wheeler Island (Fig. 27). Salinities fluctuated with precipitation patterns within Suisun Bay, while the Delta remained fresh. In spring 2012, the only Delta site measured was Fisherman's Cut, which remained fresh into May, while all Suisun Bay sites increased in salinity with a peak of 4.4 ppt at the most western site, Ryer Island (Fig. 28). Suisun sites also experienced increasing salinities throughout the month of May. In summer 2012, all Delta sites remained fresh. In Suisun Bay, the salinity gradient increasing from east to west was still present with a peak of 8 ppt at Ryer Island (Fig. 29). Suisun sites fluctuated together with unknown fresh (July 11$^{th}$) and salty events (July 17$^{th}$). Following the dry and hot summer months, salinities reached their highest levels in October 2012 (Fig. 30). One Delta site, Sherman Lake, even reached a salinity high of 2.1 ppt. Ryer Island remained the most saline with highs reaching 10.1 ppt (Fig. 30).

***Temperature*.** In February 2012, all sites experienced similar temperature ranges between 9-12.5 °C (Fig. 31). Sites that were located close in geography tended to display similar temperature patterns. Suisun Bay sites, Wheeler, Chipps, and Winter Islands all experienced similar variations in temperature, while Sherman Lake and Big Break (in the confluence) were also similar. The two most eastern sites, Decker Island and Fisherman's Cut also demonstrated similar temperature trends (Fig. 31). However, in spring 2012 (May), all sites measured followed extremely similar temperature patterns regardless of geographic location and all sites increased in temperature compared to the winter season (Fig. 32). In summer 2012 (July), sites again followed similar temperature patterns with a range of 21-24 °C (Fig. 33). There was a slight temperature gradient with

warmer temperatures in the eastern reaches of the Delta and cooler temperatures at the western ranges. By fall in October 2012, all sites began to cool with a lower range of 17-22 °C (Fig. 34).

All SAV beds also experienced warmer temperatures than compared to adajcent-open waters. In July 2012, all sites with full datasets: Ryer Island, Chipps Island, Winter Island, and Fisherman's Cut experienced ~3% higher temperatures within SAV beds than outside the beds (Fig. 35). In September 2012, percent differences between inside and outside beds increased from western to eastern sites. Ryer Island's SAV beds were 2.6% warmer, while Winter Island was 3.2% warmer, and Sherman Lake was 5.5% warmer (Fig. 36). A similar trend occurred in October 2012, where the western end of Suisun Bay experienced ~3% difference and Sherman Lake experienced a 4.9% difference, and Big Break's SAV bed was 4.1% warmer (Fig. 37).

***Light Attenuation*.** Light attenuation through the water column was calculated for each site (Fig. 38). Higher values indicate less light penetration, which may correspond with turbidity of the water column. There are few patterns that distinguish Detla and Suisun sites in our data, however, it is clear that light attenuation fluctuates seasonally. Decker Island, Big Break, Winter Island, and Chipps Island consistently showed less light penetration within plant beds than outside of plant beds, while at Ryer Island, there was less light penetration measured outside the beds than within the beds. Wheeler Island showed no differences, and patterns reversed according to the season at at Sherman Lake and Fisherman's Cut.

**FIGURES**

Figure 1. Native SAV beds dominated by *Stuckenia* spp. at Ryer, Wheeler, Chipps, and Winter Islands in Suisun Bay and invasive SAV beds dominated by *Egeria densa* at Sherman Island, Big Break, Fisherman's Cut, and Decker Island in the western Delta.

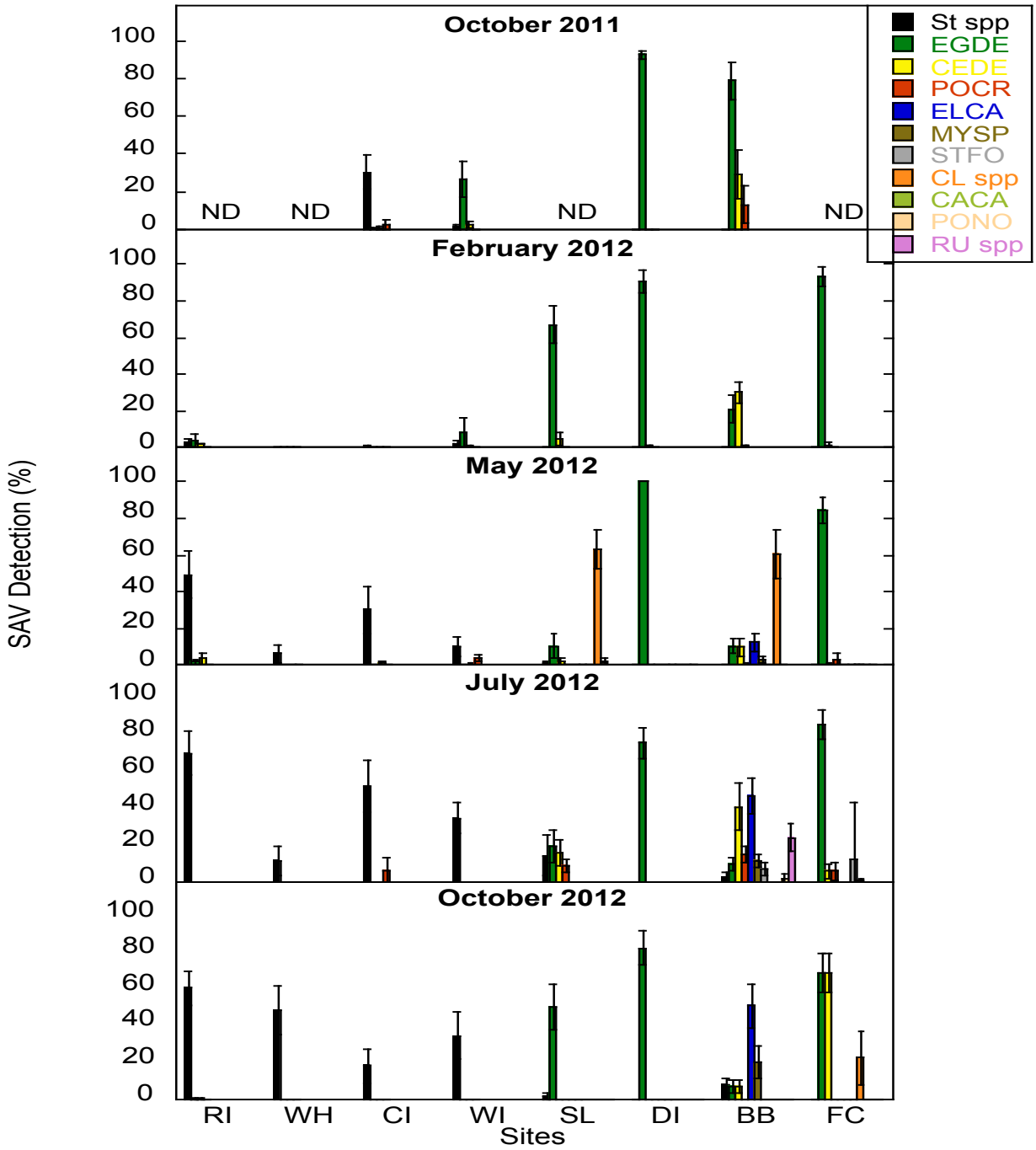



Figure 2. Percent detection values (rake method) for all quarterly sampling periods at all sites. Abbreviated species are *Egeria densa* (EDGE), *Ceratophyllum demersum* (CEDE), *Potamogeton crispus* (POCR), (n=3). *Elodea canadensis* (ELCA), *Myriophyllum spictatum* (MYSP), *Stuckenia foliosus* (STFO), *Cladophora* spp. (CL spp), *Cabomba caroliniana* (CACA), *Potamogeton nosdosus* (PONO), and *Ruppia* spp (RU spp) (n=3).

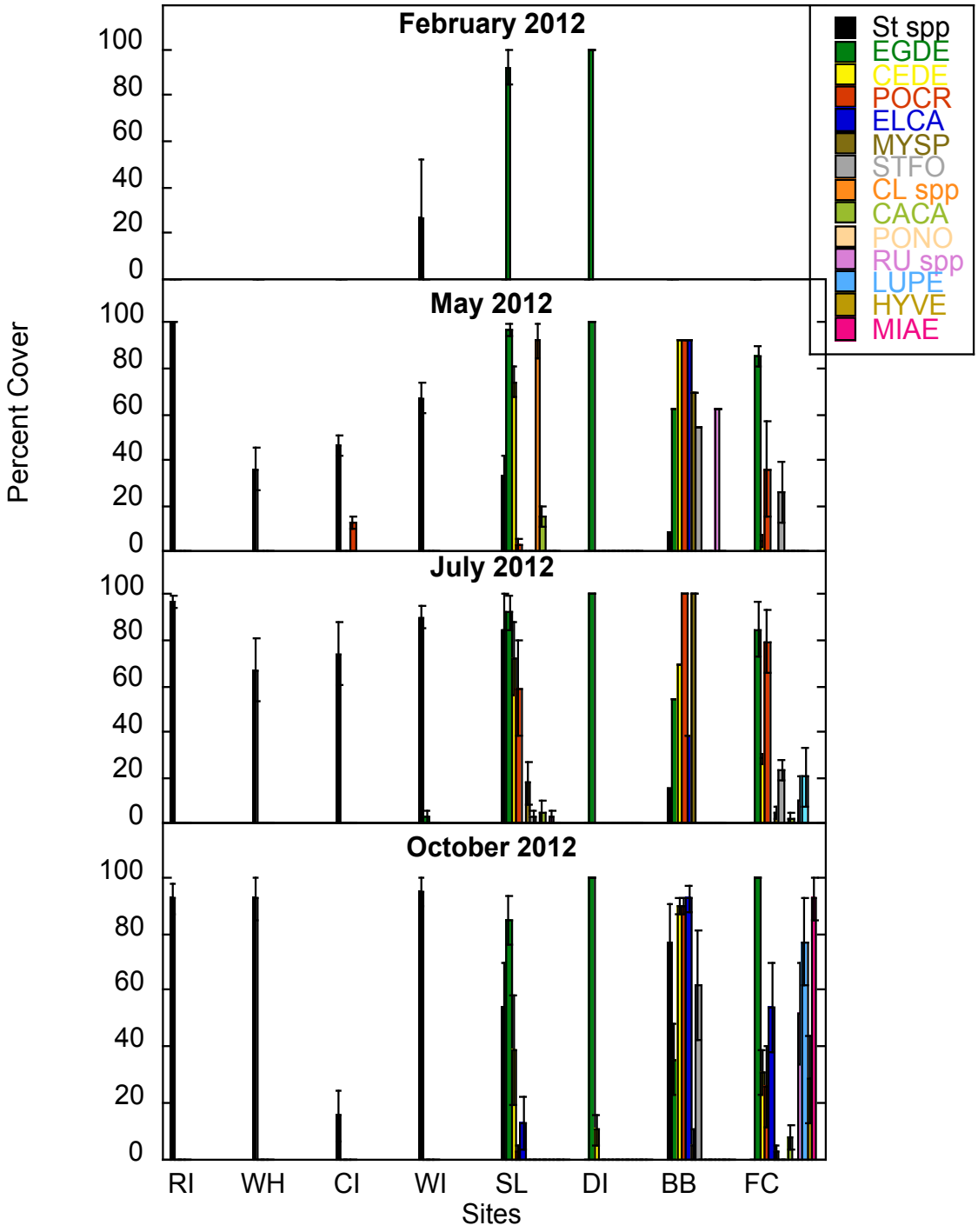



Figure 3. Percent cover for all quarterly sampling at all sites. Species abbreviations as in Figure 2 with the addition of *Ludwigia peploides* (LUPE), *Hydrocotyle verticillata* (HYVE), and *Microcystis aeruginosa* (MIAE). Big Break's spring and summer percent cover calculations were done with one transect (n=1). Decker Island's spring percent cover calculations were done with one transect (n=1). All other sites and seasons were calculated based on three transects (n=3).

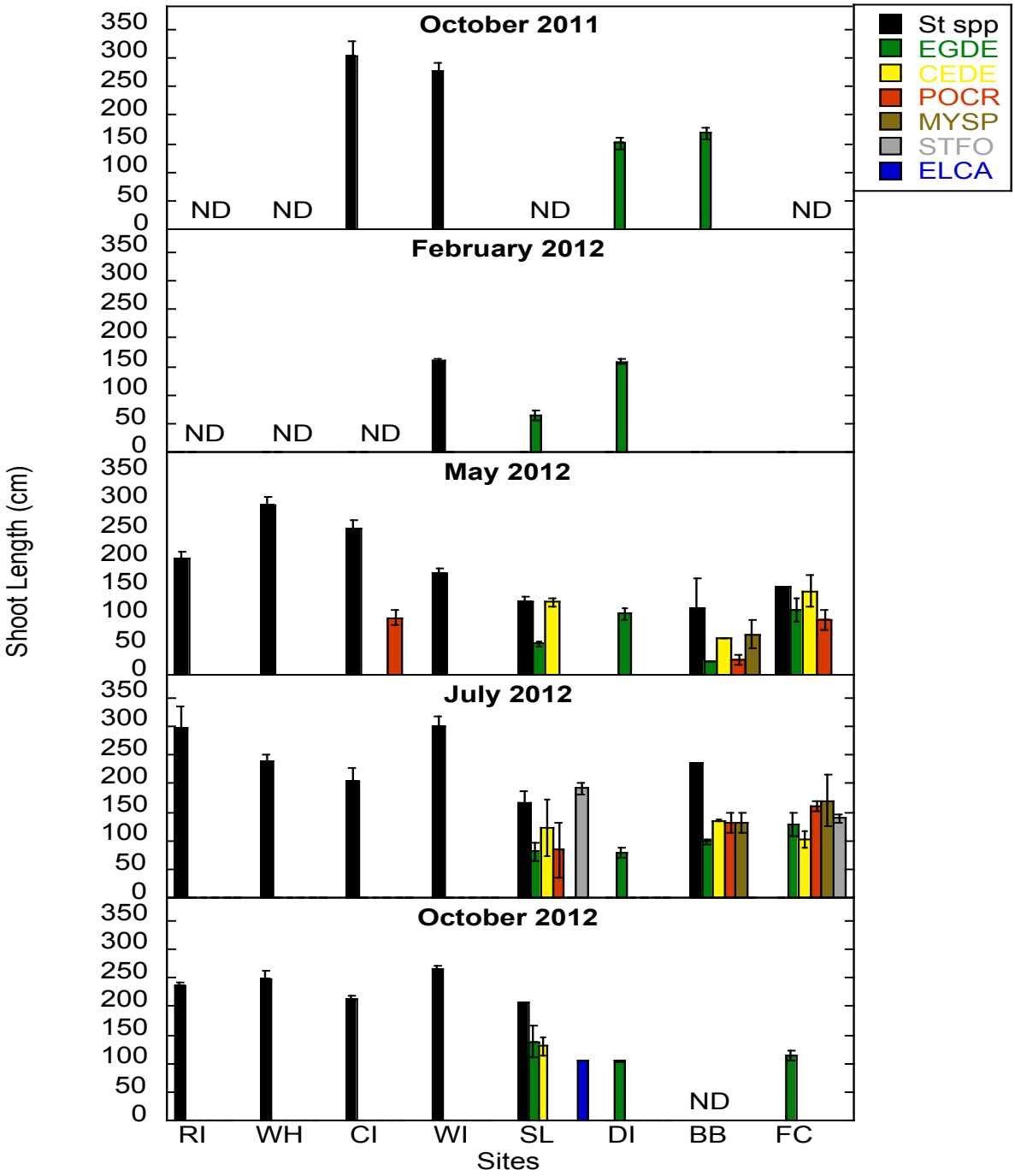



Figure 4. Average shoot lengths of dominant species for all quarterly sampling periods at all sites. Error bars represent standard error (n varies due to absence of several species along transect; typically n=3). There were no shoot lengths recorded at Big Break for fall 2012.

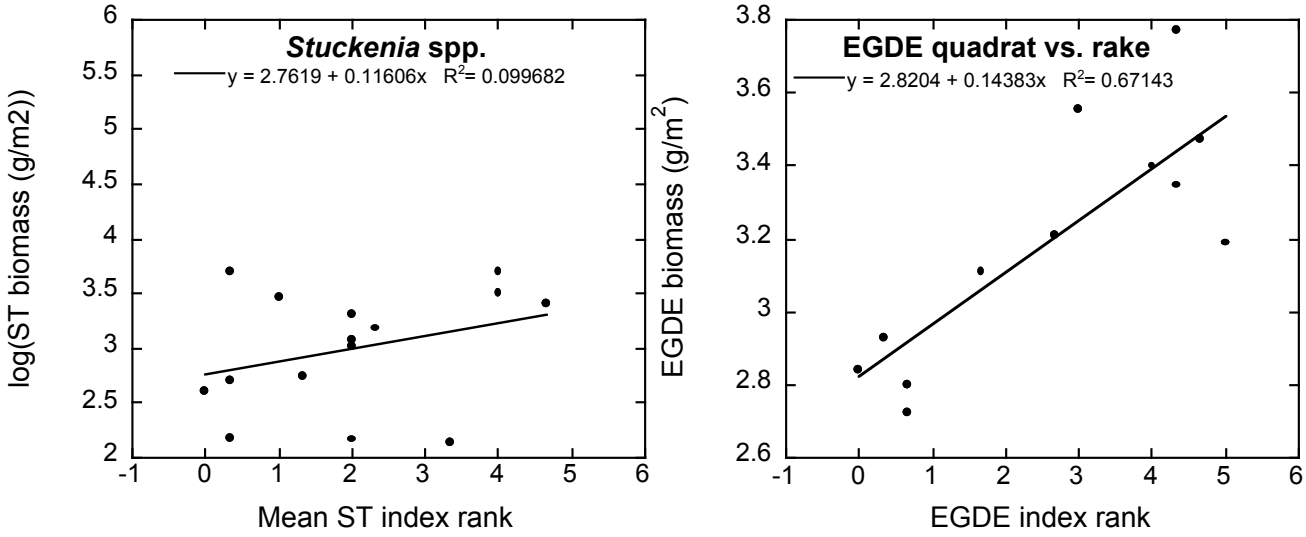



Figure 5. Scatter plot of average rake index versus plant biomass per quadrat (log10(g/m$^2$)) for *Stuckenia* spp. from Suisun Bay sites (left) and for *Egeria densa* from all western Delta sites (right; n = 3 for each point). Biomass and rake values collected on July 1$^{st}$, 2$^{nd}$, 3$^{rd}$, and 19$^{th}$ 2012.

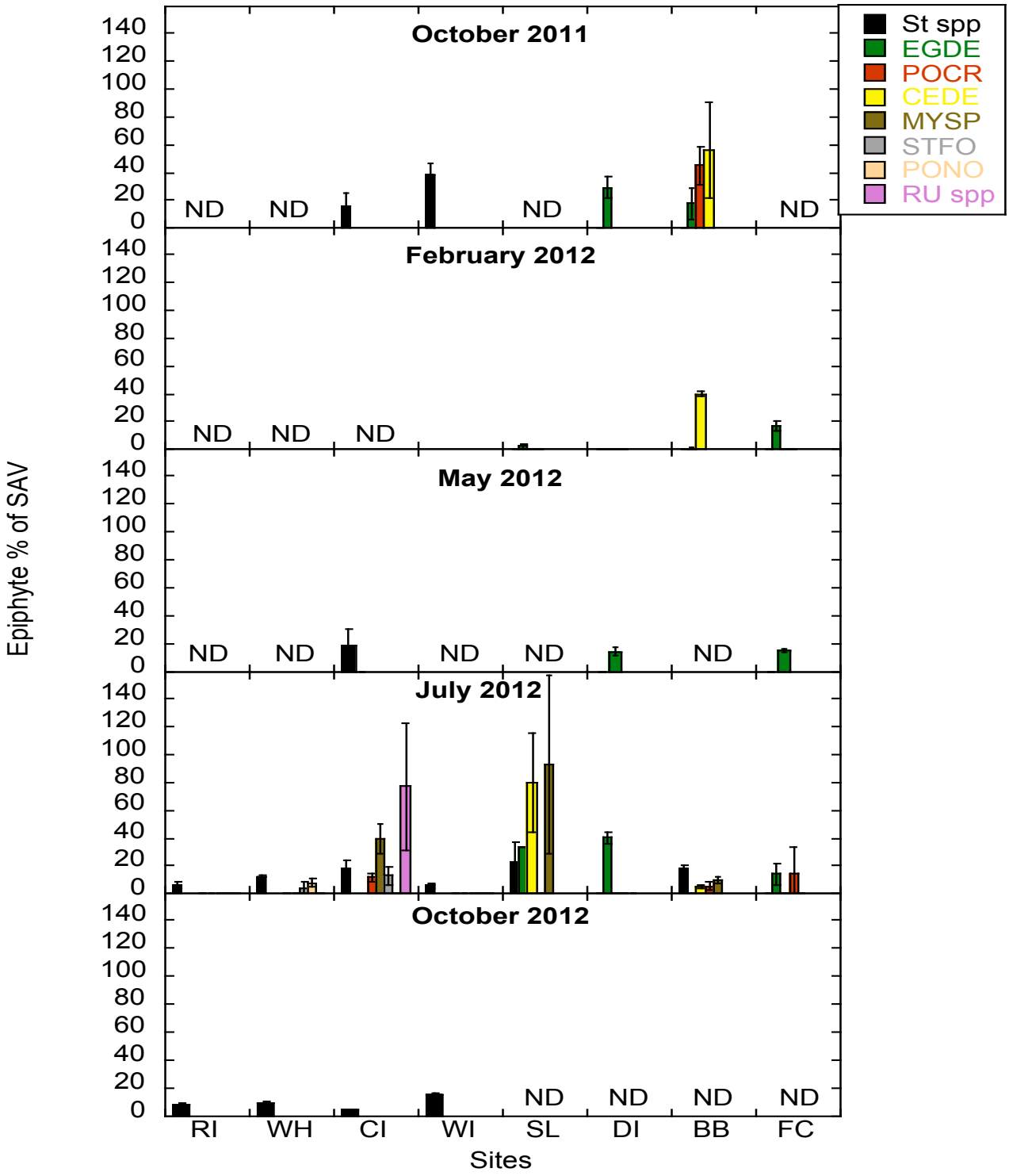



Figure 6. Epiphyte % of dry host SAV for each SAV species for each quarterly sampling period at all sites.

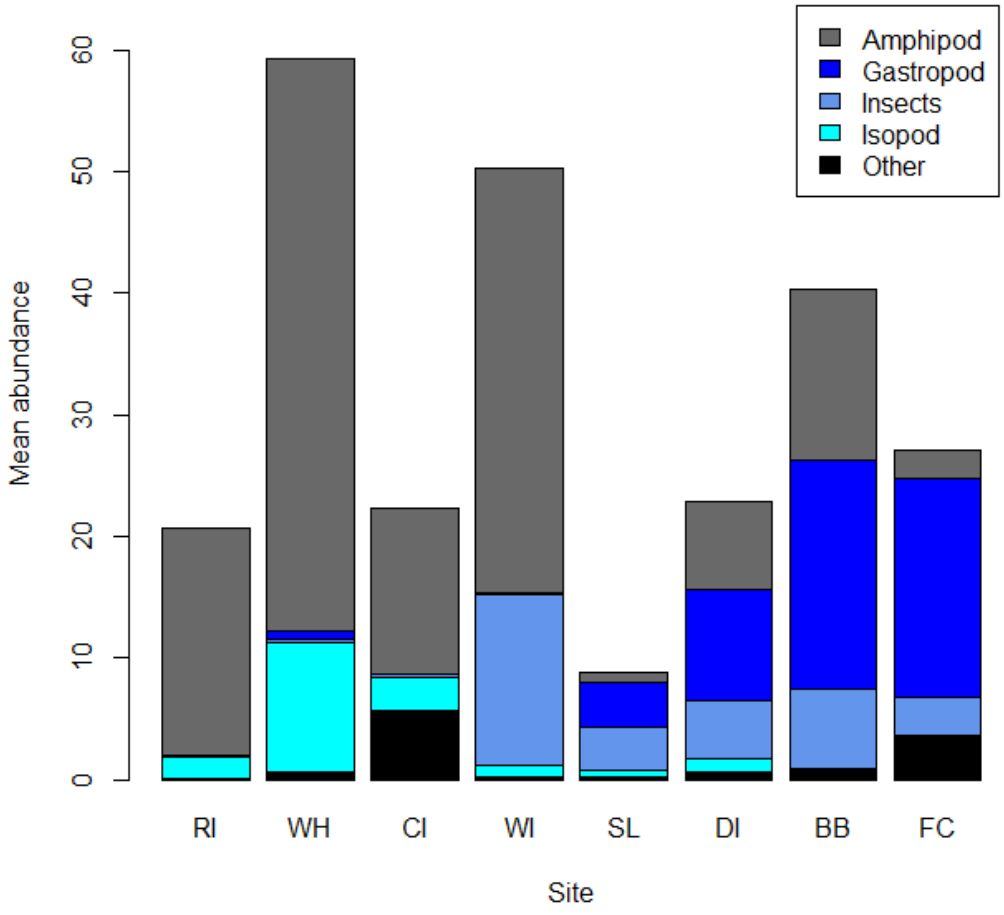



Figure 7. Mean abundance of invertebrates per sample, by site and taxa in all four seasons of 2012. RI = Ryer Island, WH = Wheeler, CI = Chipps Island, WI = Winter Island, SL= Sherman Lake, DI = Decker Island, BB = Big Break, FC = Fisherman's Cut.

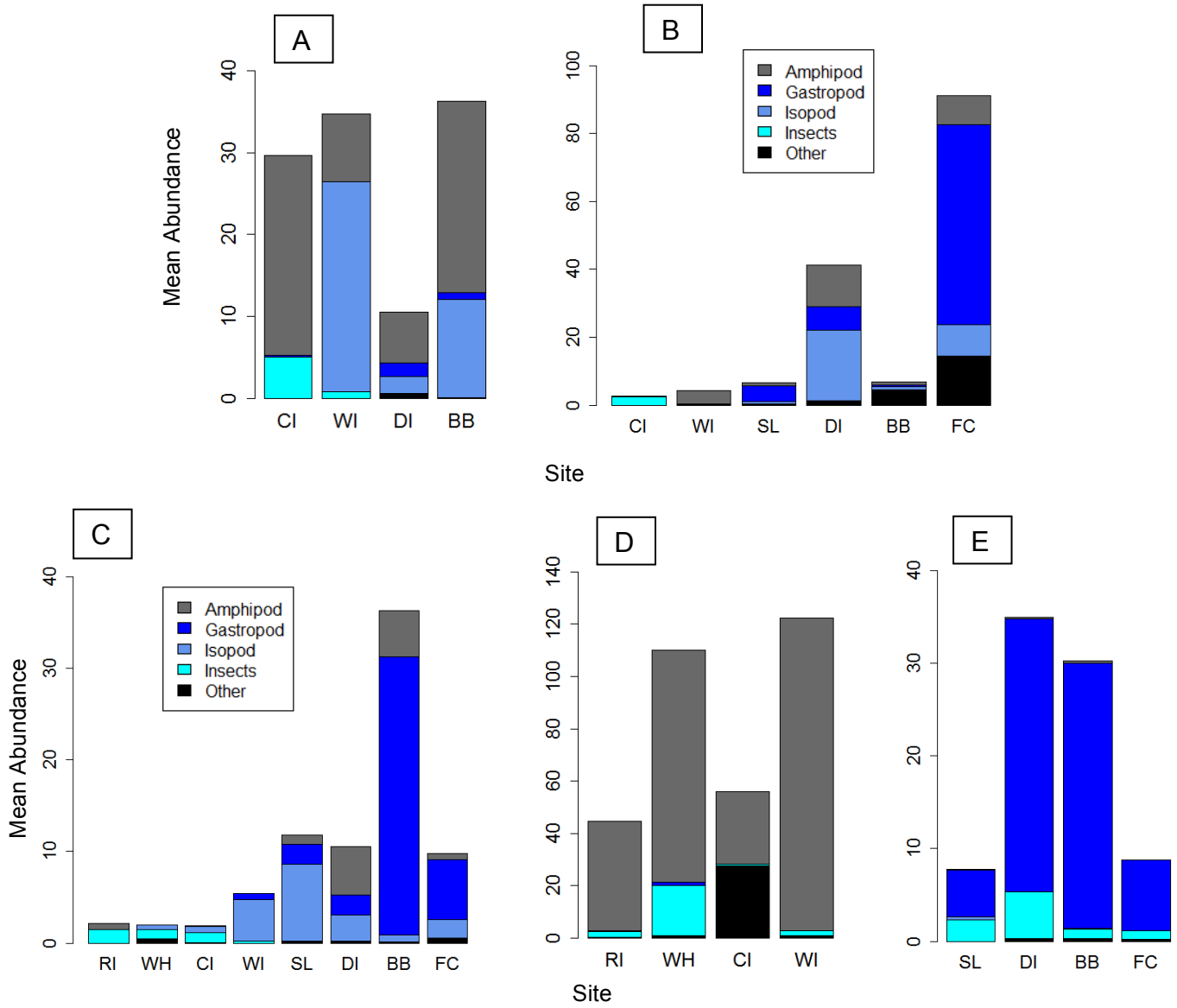
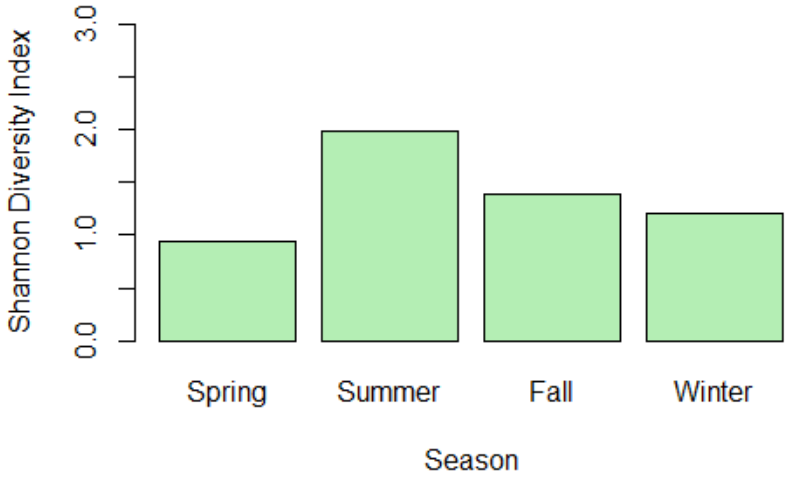



Figure 8. Mean abundance of invertebrates by site and taxa for fall 2011 and all four seasons of 2012. A = fall 2011, B = spring 2012, C = summer 2012, D = fall 2012, E = winter 2012. RI = Ryer Island, WH = Wheeler, CI = Chipps Island, WI = Winter Island, SL= Sherman Lake, DI = Decker Island, BB = Big Break, FC = Fisherman's Cut. In spring 2012 there were no invertebrates on samples from RI or WH. In fall 2012 no Delta sites were visited and in winter 2012 Suisun plants were not available for invertebrate sampling due to nearly complete senescence. The y axes vary to accommodate different abundances.



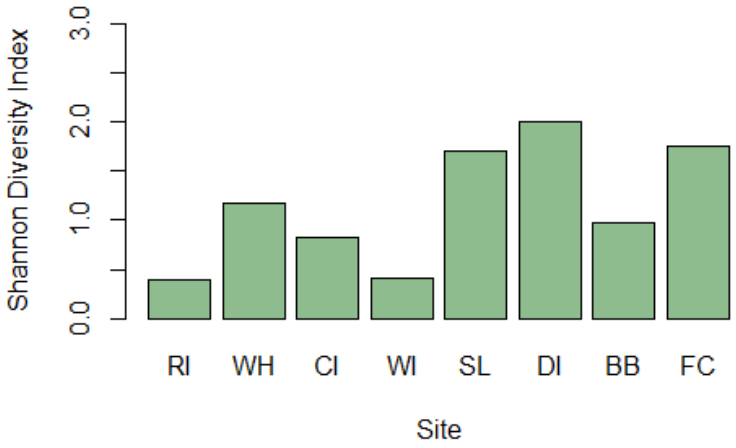




Figure 9. Shannon Diversity Indices, based on the mean invertebrate abundances in each season in 2012 (top), and each site (bottom).

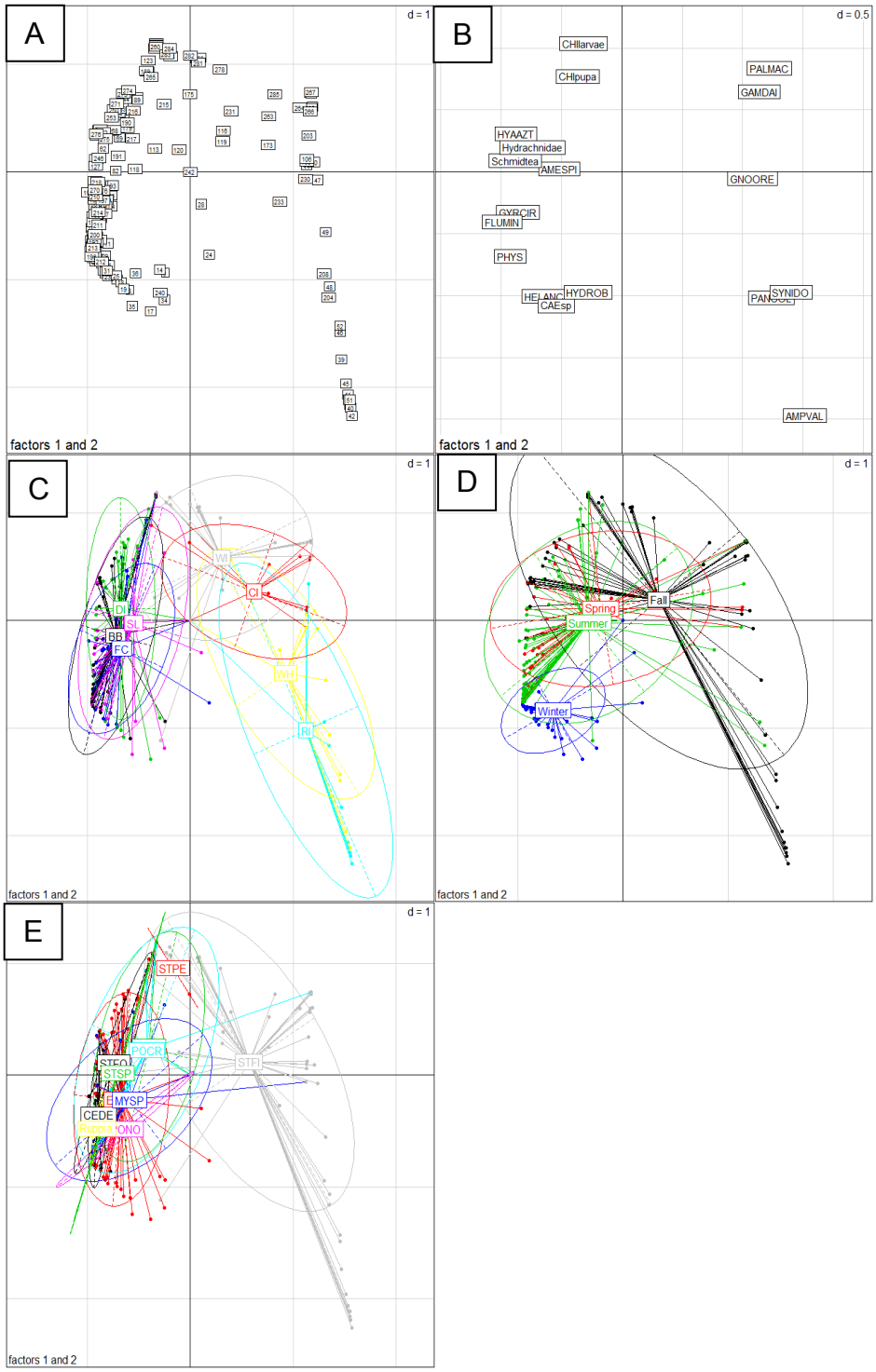



Figure 10. Graphical output of the Correspondence Analysis showing the variabiltiy of invertebrate species abundance explained by two axes. Axis 1 runs along the bottom of each plot, axis 2 runs along the left edge of each plot. A = sample variation, B = invertebrate species allocated to each sample, C= site influence to invertebrate species variation, D = seasonal influence to invertebrate species variation, and E = SAV influence to invertebrate species variation.

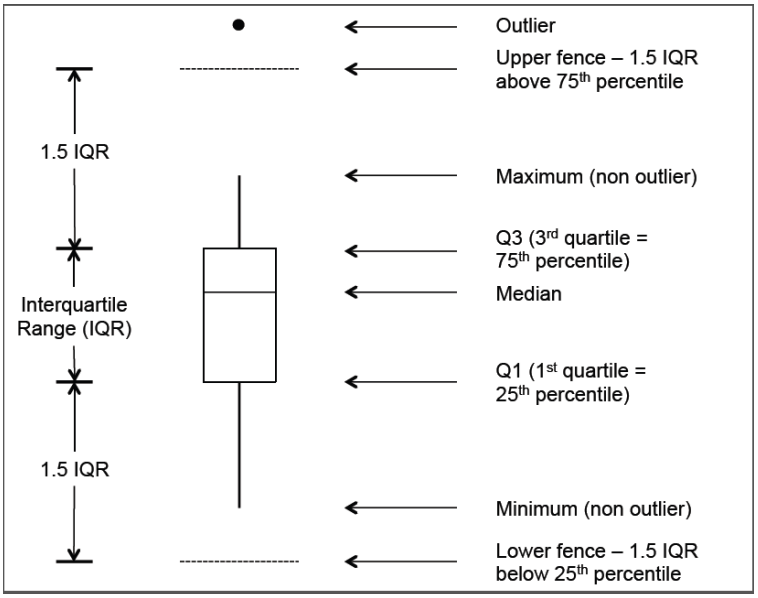



Figure 11. Diagram explaining the distribution of data within a boxplot for reference when looking at upcoming figures.

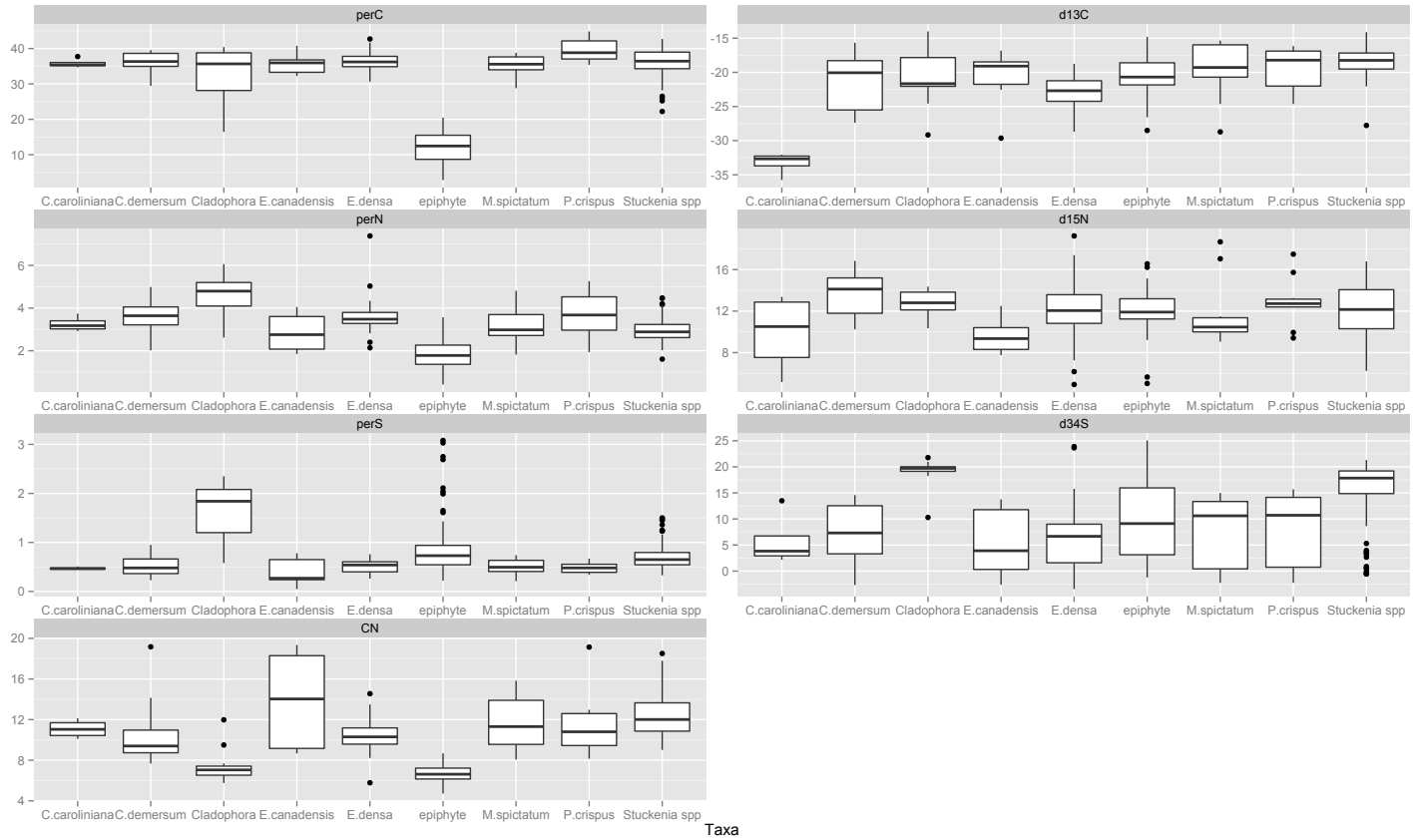



Figure 12. C, N and S percent composition (perC, perN, perS in %), C/N ratio (CN, no units), and stable isotope composition expressed as $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ (d13C, d15N, d34S in ‰) in the different plant taxa collected in the course of this project (all sites and sampling seasons).

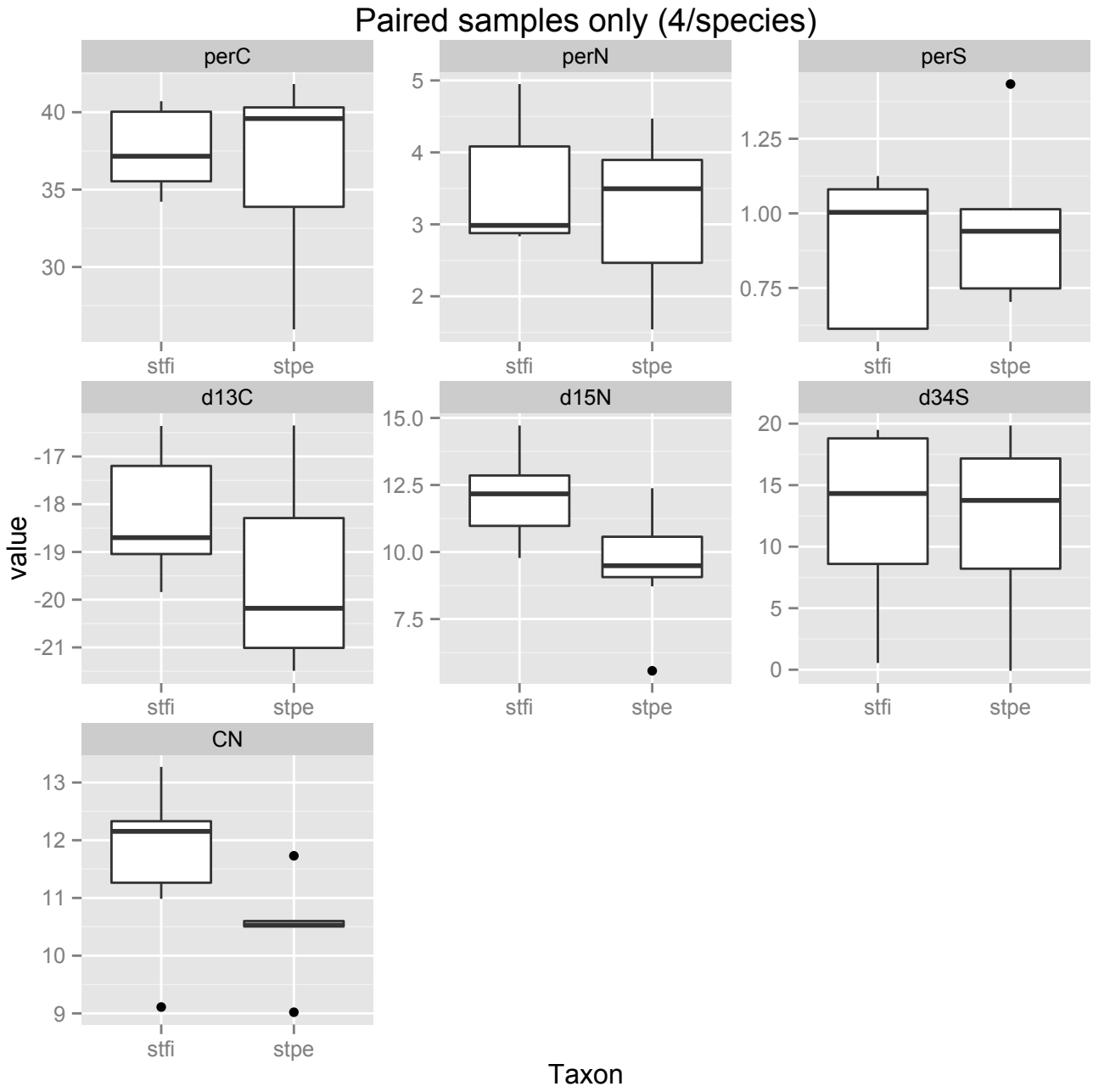



Figure 13. Differences between *Stuckenia filiformis* (stfi) and *Stuckenia pectinata* (stpe) in C, N and S percent composition (perC, perN, perS in %), C/N ratio (CN, no units), and stable isotope composition expressed as $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ (d13C, d15N, d34S in ‰).

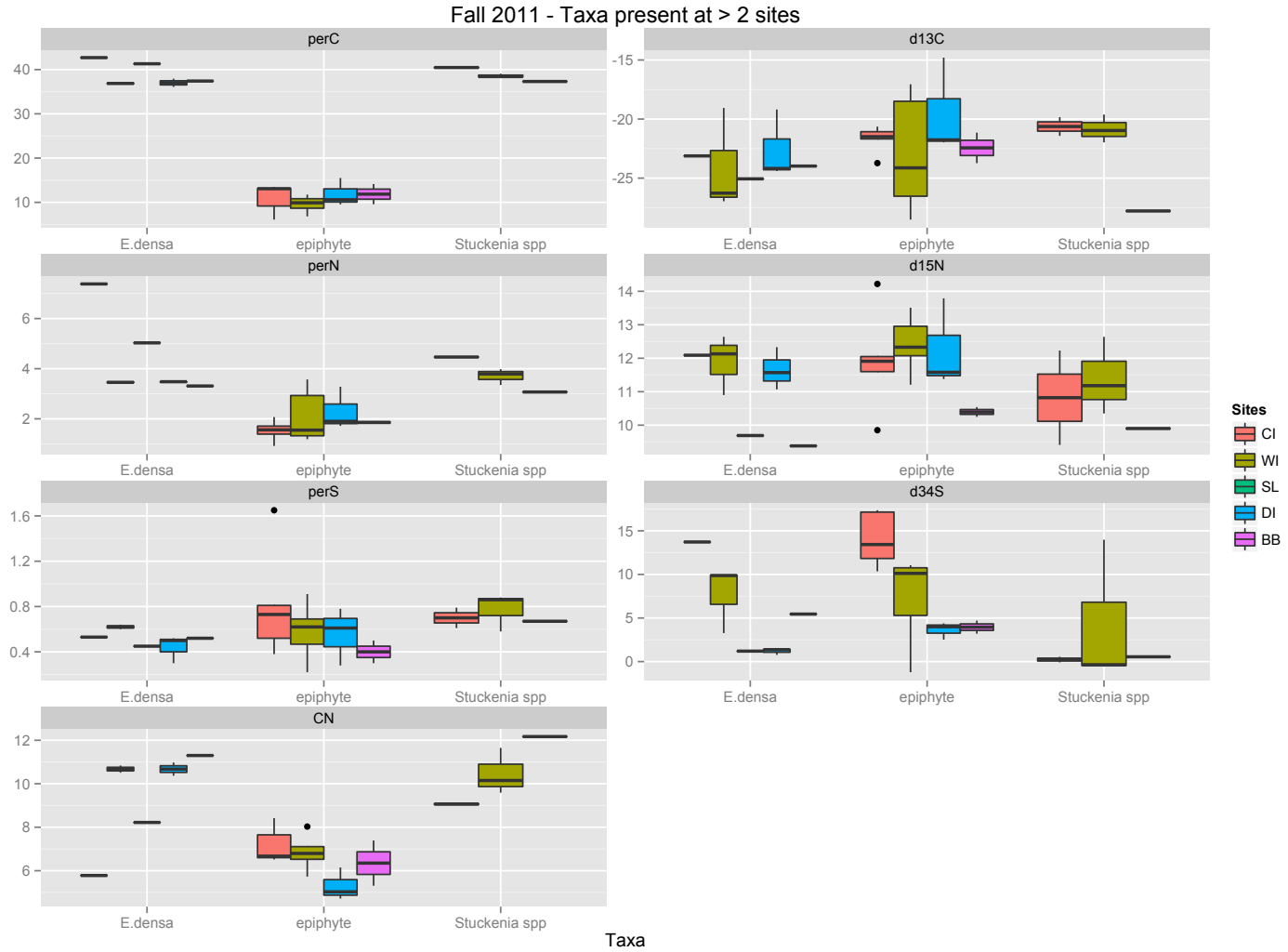



Figure 14. For the 3 most widespread plant and algae taxa in Fall 2011 (*Egeria densa*, epiphytes and *Stuckenia* spp.), inter-sites differences in C, N and S percent composition (perC, perN, perS in %), C/N ratio (CN, no units), and stable isotope composition expressed as $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ (d13C, d15N, d34S in ‰). Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB).

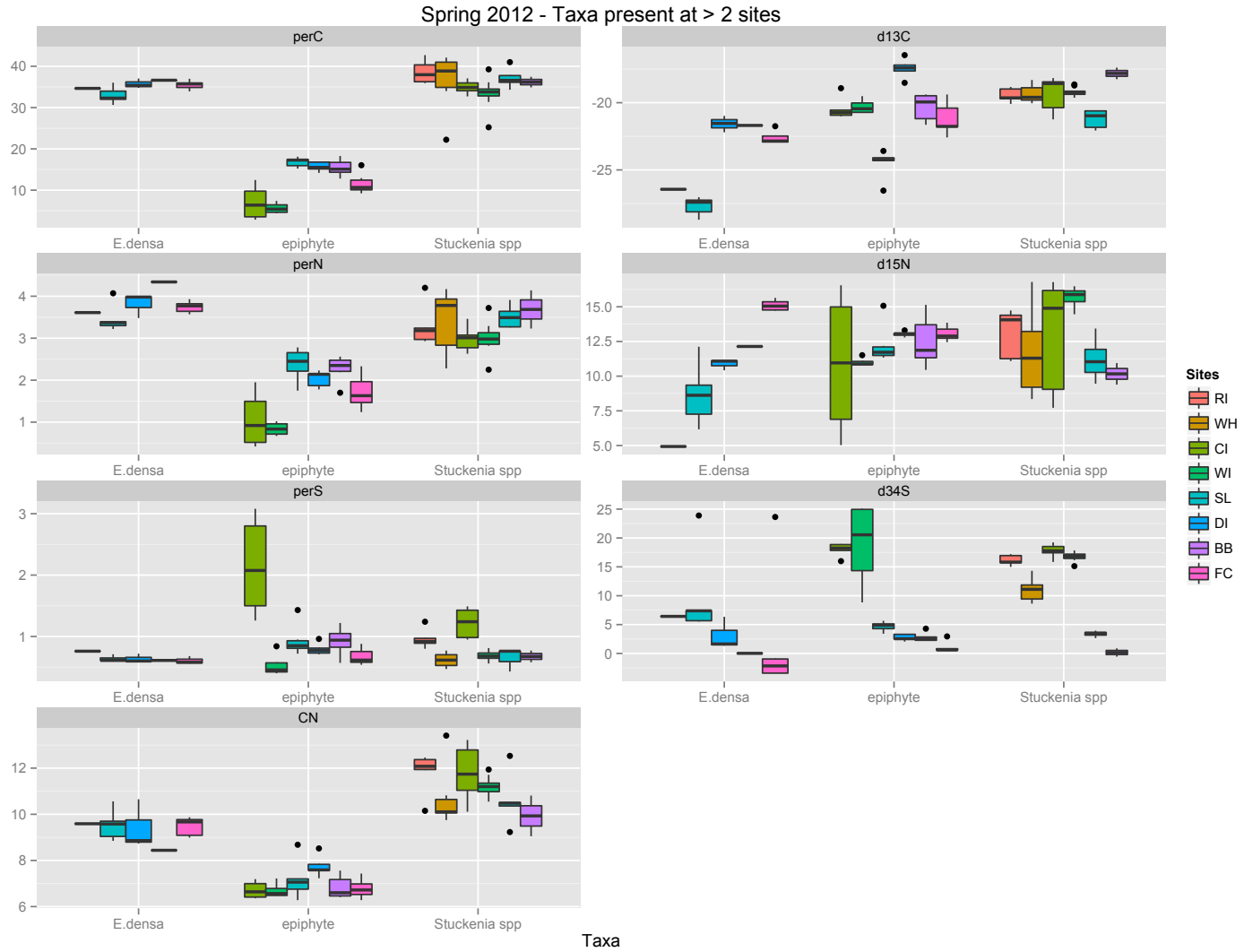



Figure 15. For the 3 most widespread plant and algae taxa in spring 2012 (*Egeria densa*, epiphytes and *Stuckenia* spp.), inter-sites differences in C, N and S percent composition (perC, perN, perS in %), C/N ratio (CN, no units), and stable isotope composition expressed as $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ (d13C, d15N, d34S in ‰). Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

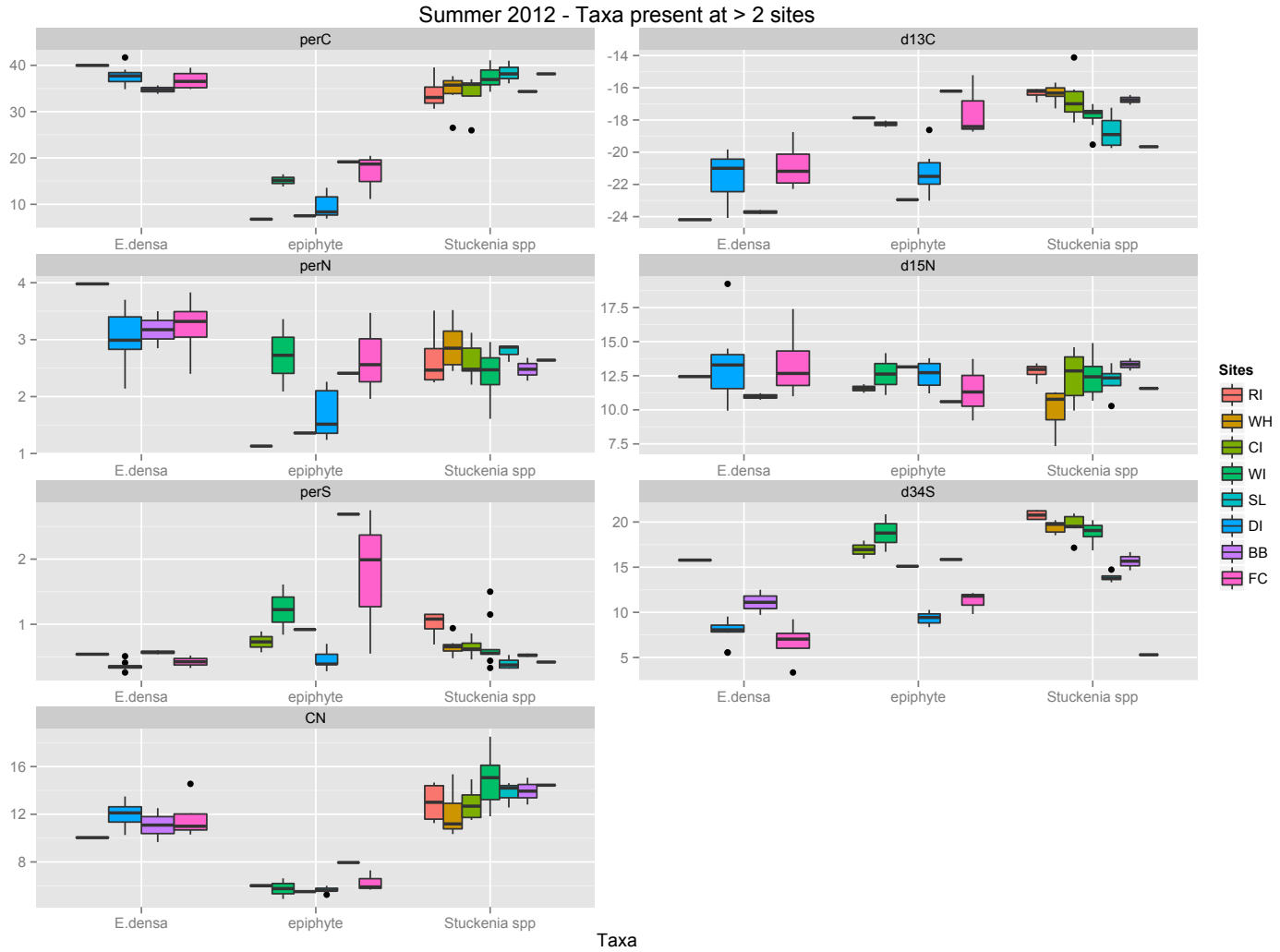



Figure 16. For the 3 most widespread plant and algae taxa in summer 2012 (*Egeria densa*, epiphytes and *Stuckenia* spp.), inter-sites differences in C, N and S percent composition (perC, perN, perS in %), C/N ratio (CN, no units), and stable isotope composition expressed as $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ (d13C, d15N, d34S in ‰). Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

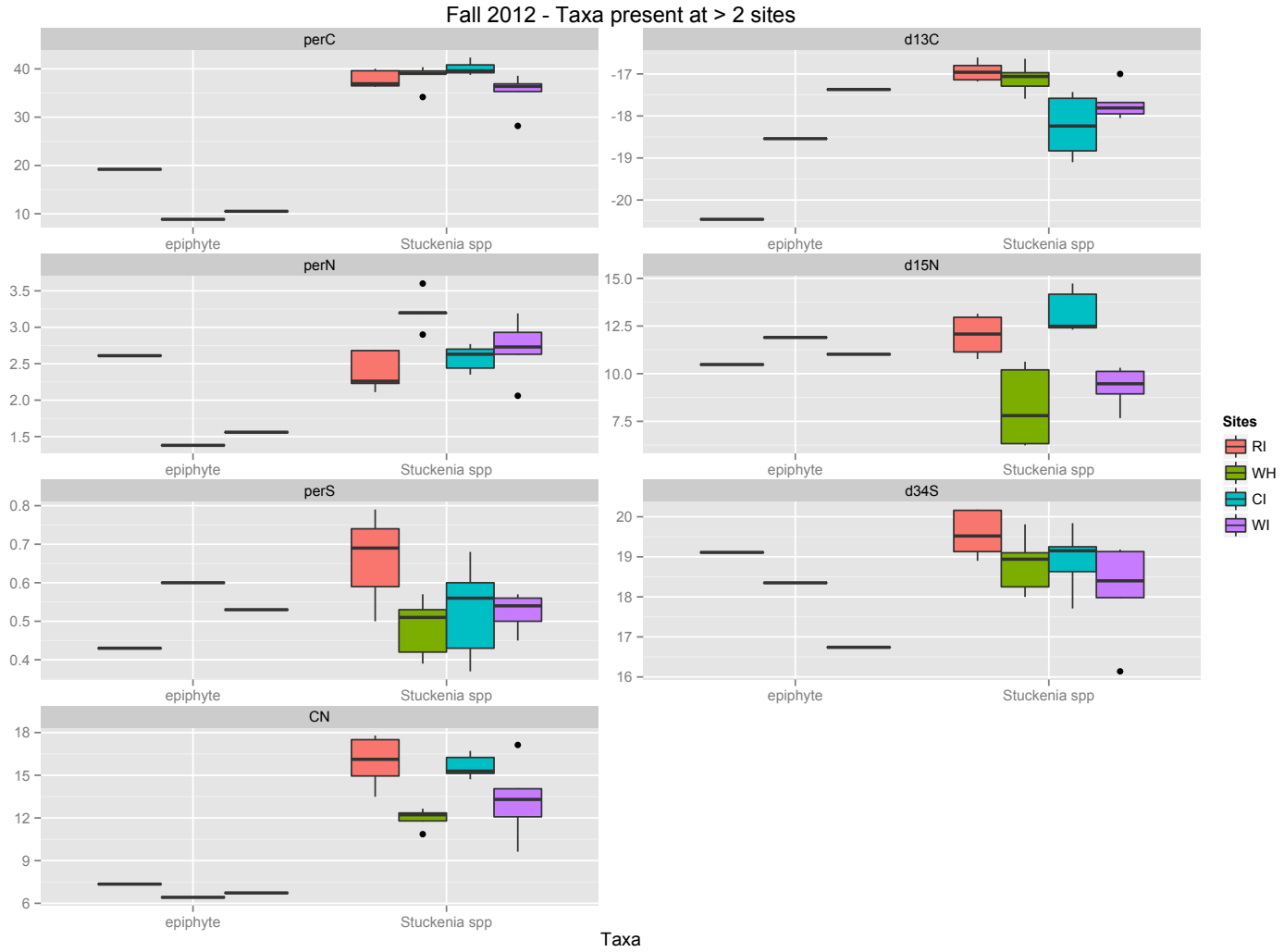



Figure 17. For the 3 most widespread plant taxa and algae in Fall 2012 (*Egeria densa*, epiphytes and *Stuckenia* spp.), inter-sites differences in C, N and S percent composition (perC, perN, perS in %), C/N ratio (CN, no units), and stable isotope composition expressed as $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ (d13C, d15N, d34S in ‰). Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI).

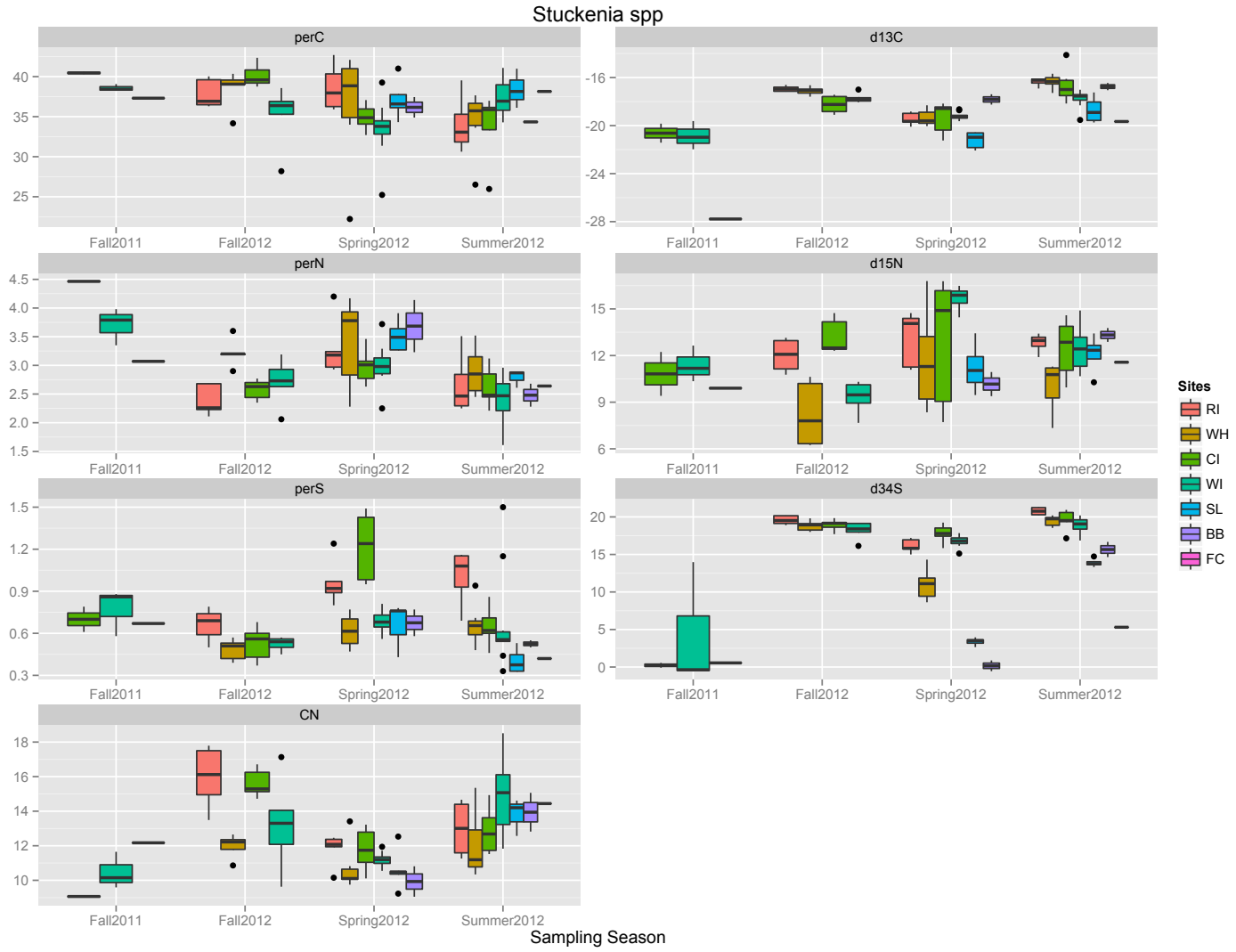



Figure 18. Spatio-seasonal variations in C, N and S percent composition (perC, perN, perS in %), C/N ratio (CN, no units), and stable isotope composition expressed as $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ (d13C, d15N, d34S in ‰) in *Stuckenia* spp. Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Big Break (BB), Fisherman's Cut (FC).

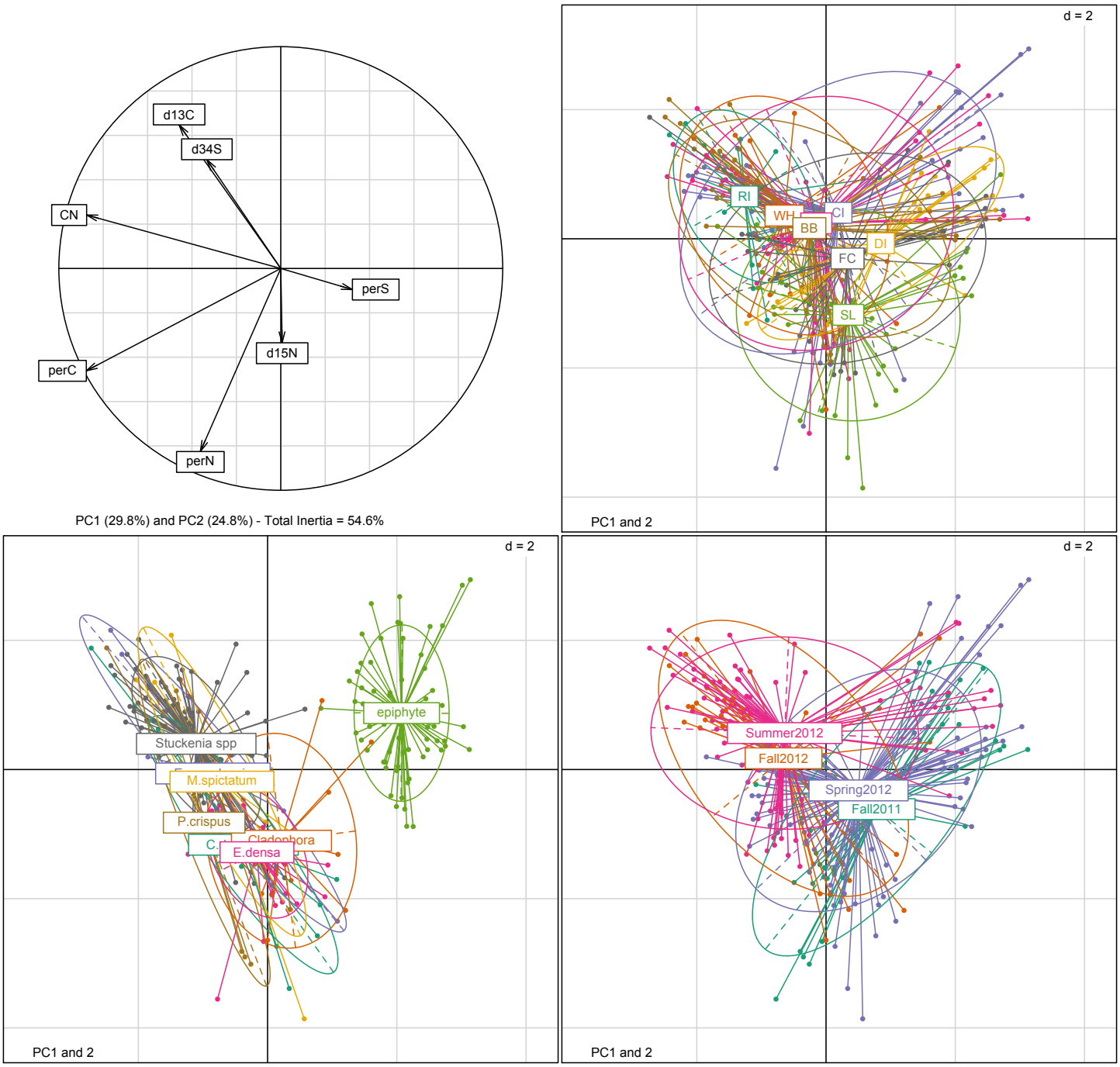



Figure 19. PCA results on plant elemental and isotopic composition. Principal components 1 and 2 are plotted for elemental and isotopic variables with correlation circle (top left), and for samples (3 others) colored by site (top right), taxa (bottom left) and season (bottom right).

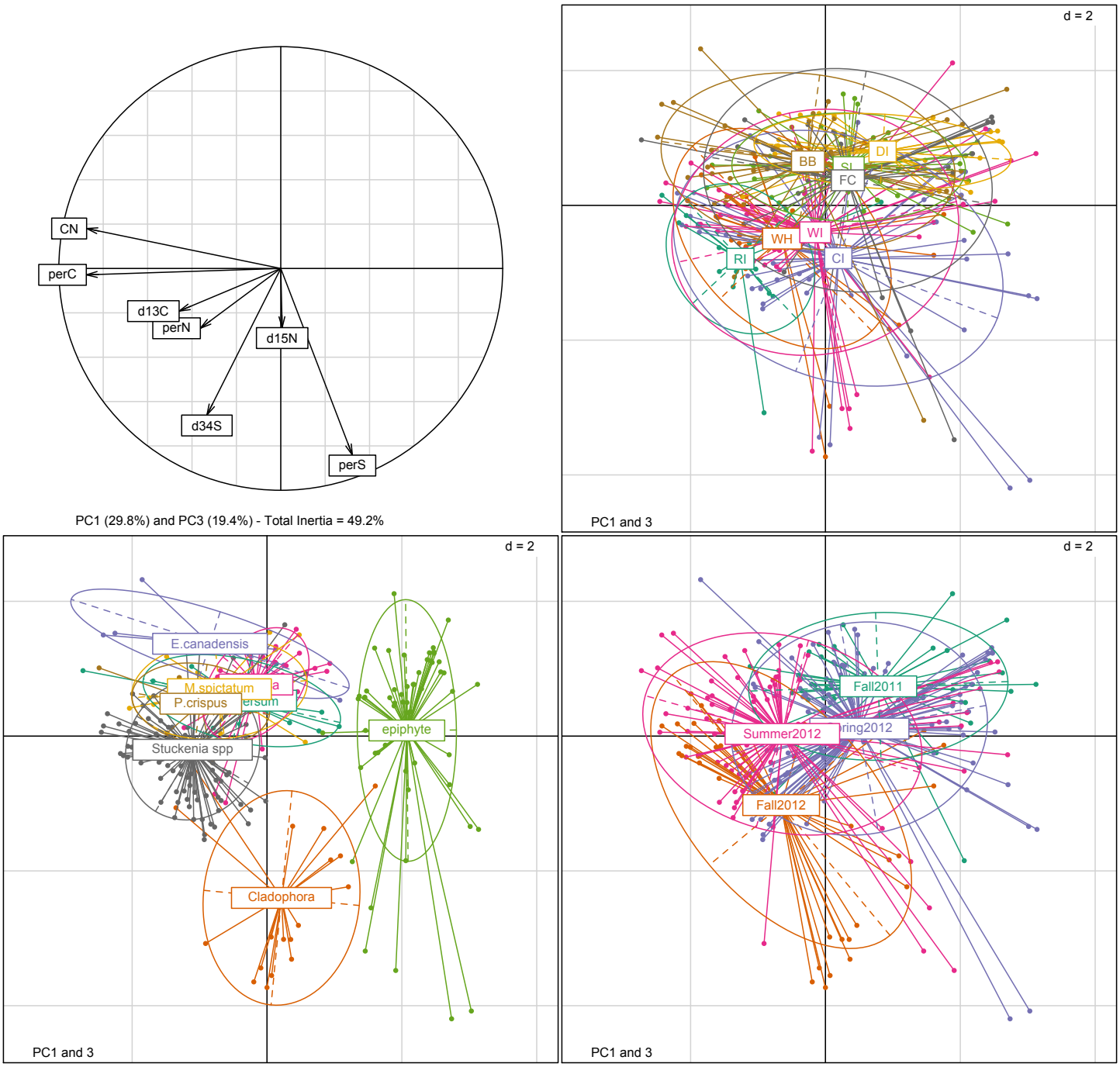



Figure 20. PCA results on plant elemental and isotopic composition. Principal components 1 and 3 are plotted for elemental and isotopic variables with correlation circle (top left), and for samples (3 others) colored by site (top right), taxa (bottom left) and season (bottom right).

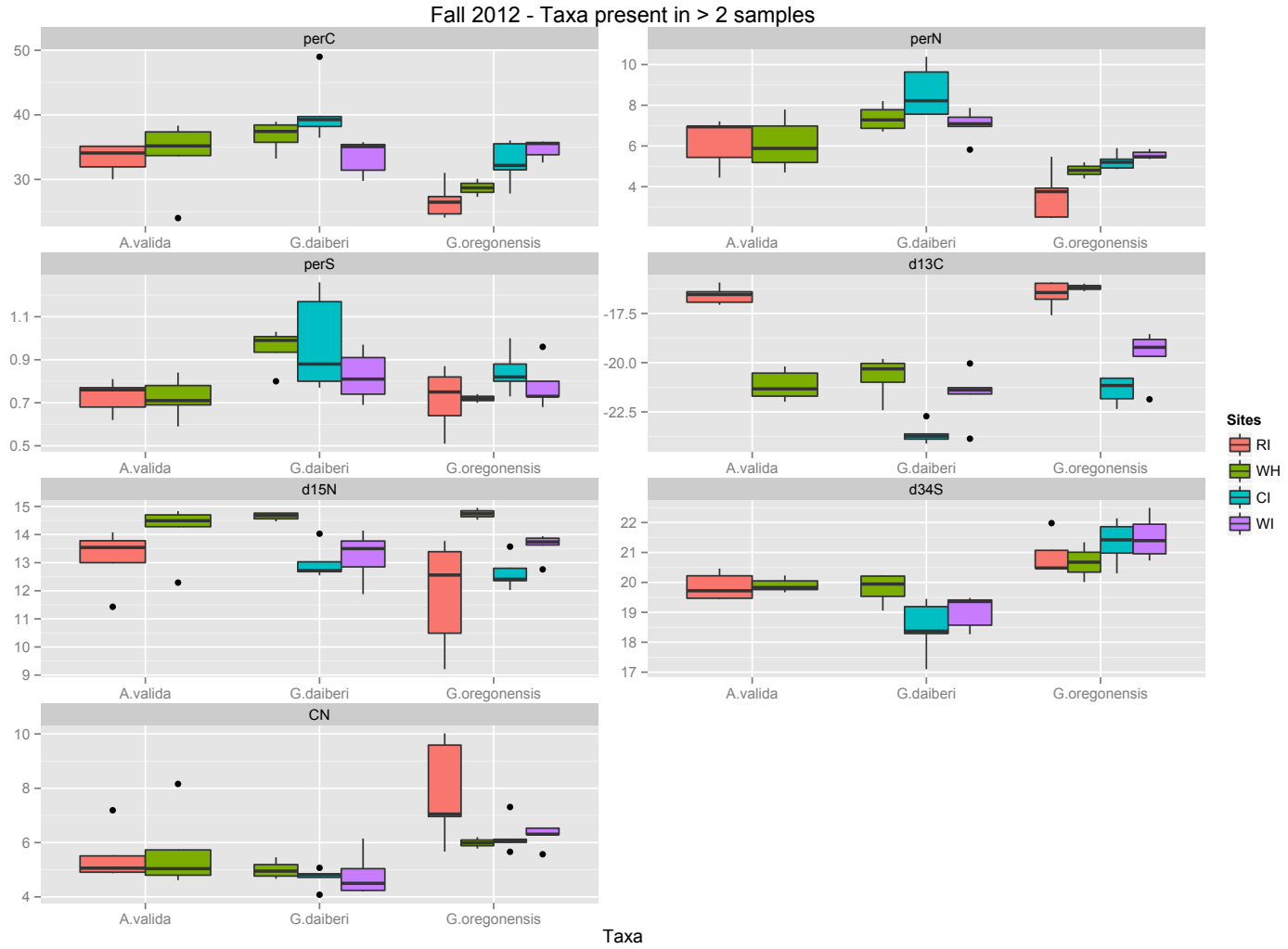



Figure 21. Spatial variations in C, N and S percent composition (perC, perN, perS in %), C/N ratio (CN, no units), and stable isotope composition expressed as $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ (d13C, d15N, d34S in ‰) for the 3 most abundant invertebrate species in fall 2012 (*Amphitoe valida*, *Gammarus daiberi*, *Gnorimosphaeroma oregonensis*). Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

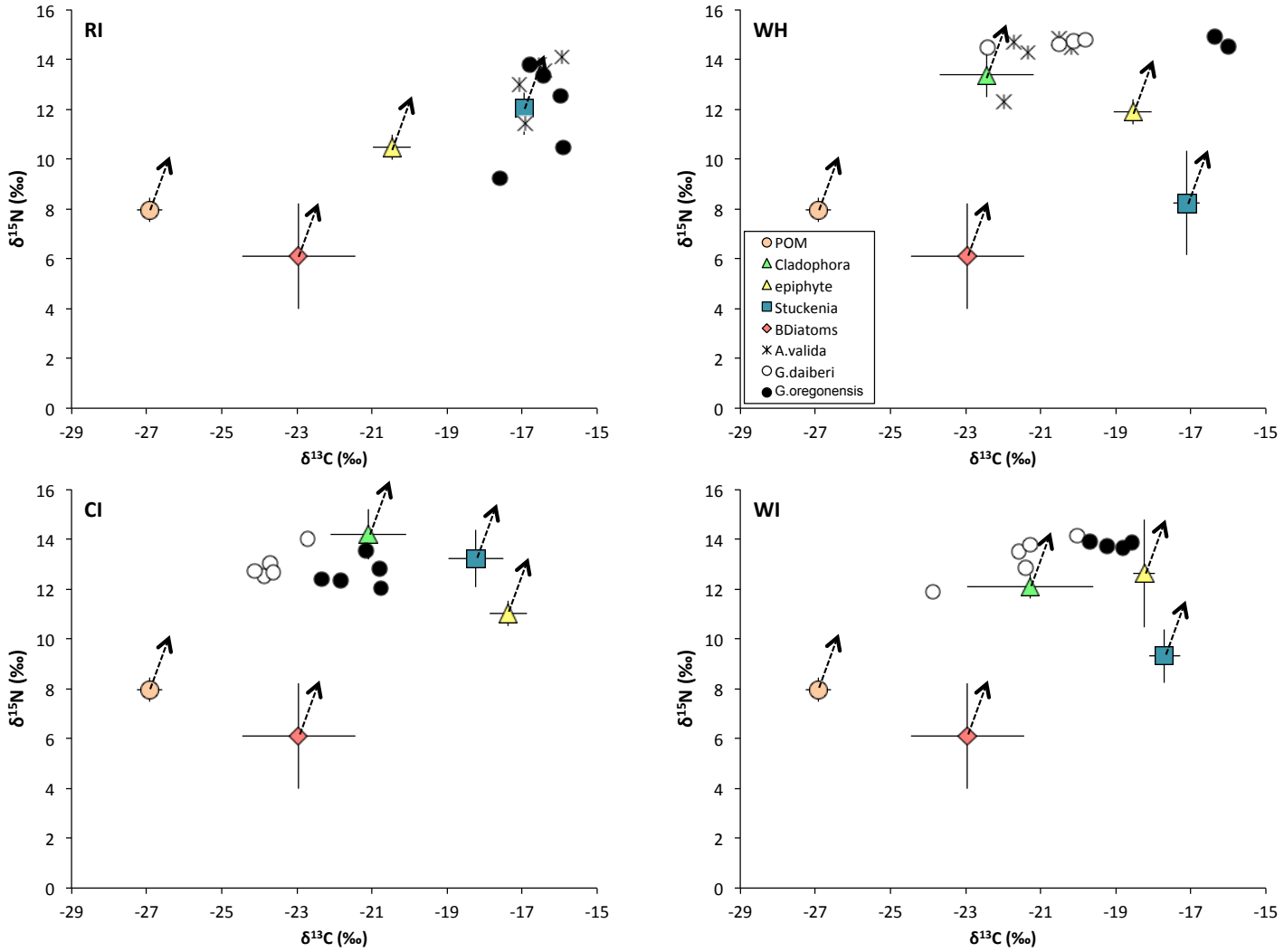



Figure 22. Dual isotope plots of $\delta^{13}C$ vs $\delta^{15}N$ (‰) for potential organic matter sources / primary producers (color, mean ± SD) and invertebrate consumers (black stars, black or white dots) at each Suisun site in fall 2012. Particulate Organic Matter (POM) and microphytobenthos (Bdiatoms) are mean values for the general area (same for each site), while *Cladophora*, epiphytes and *Stuckenia* spp. are specific to each site. Arrows depicts typical trophic enrichment factors (TEF) for aquatic consumers feeding on low protein or vascular plants sources (McCutchan et al., 2003).

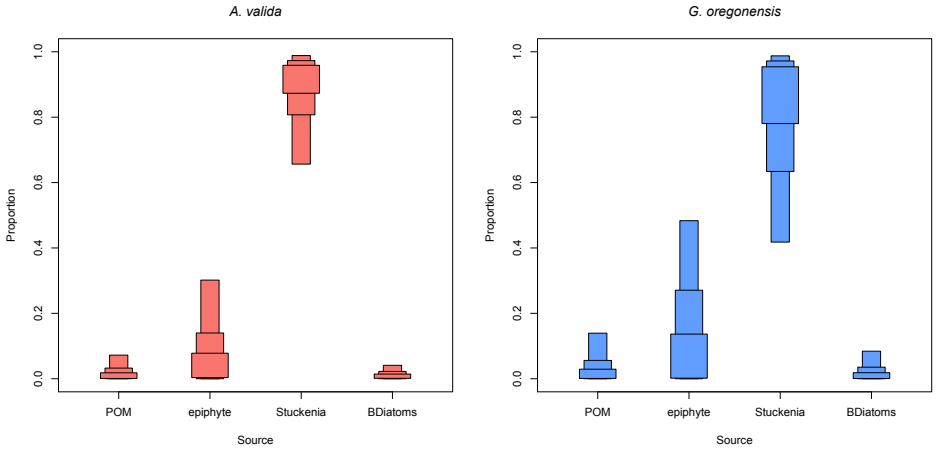



Figure 23: **RI -** Output of the SIAR mixing model for invertebrate consumers (*Amphitoe valida*, red; *Gnorimosphaeroma oregonensis,* blue) found at Ryer Island in fall 2012. Boxplot of dietary proportions for the different sources availble depicts 25, 75 and 95% credibility intervals.

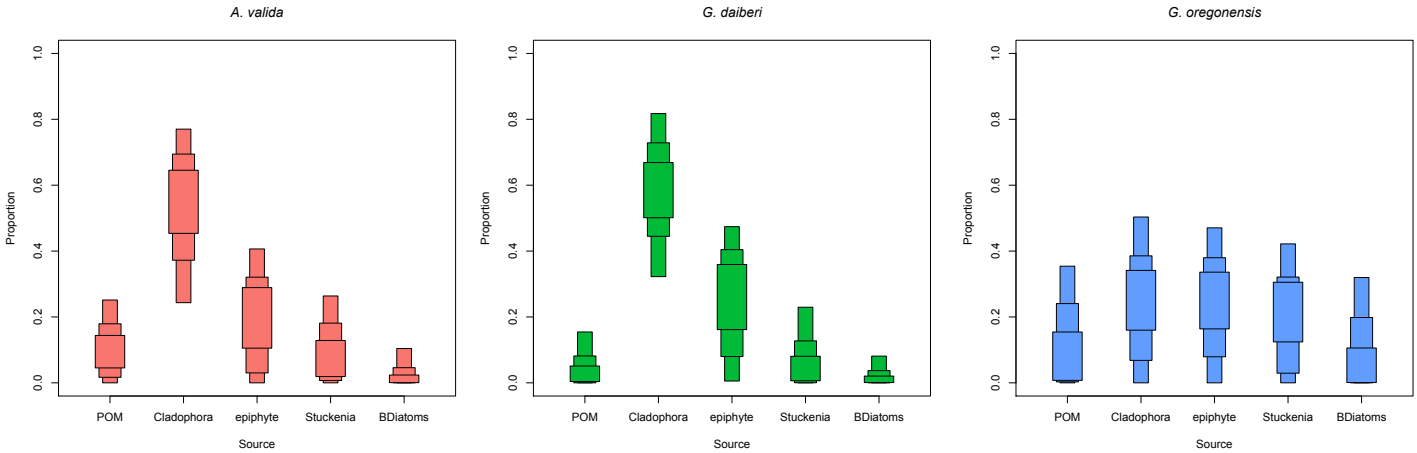



Figure 24: **WH -** Output of the SIAR mixing model for invertebrate consumers (*Amphitoe valida*, red; *Gammarus daiberi*, green; *Gnorimosphaeroma oregonensis,* blue) found at Wheeler Island in fall 2012. Boxplot of dietary proportions for the different sources availble depicts 25, 75 and 95% credibility intervals.

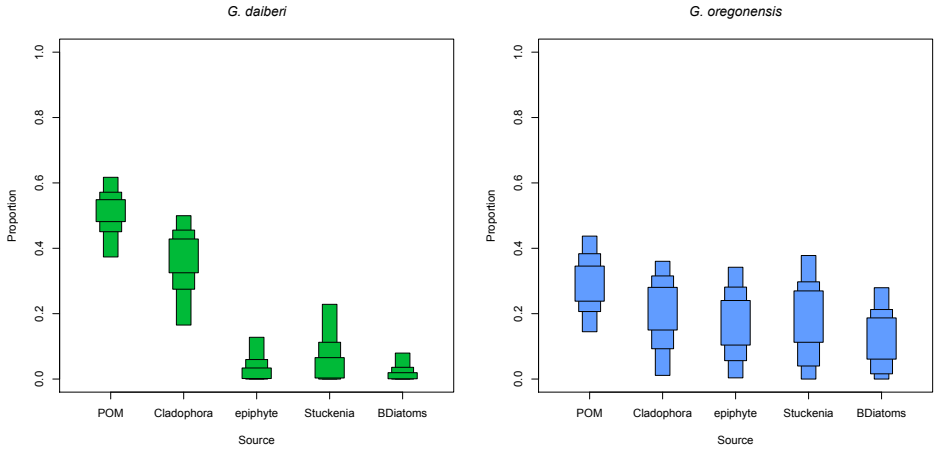



Figure 25: **CI -** Output of the SIAR mixing model for invertebrate consumers (*Gammarus daiberi*, green; *Gnorimosphaeroma oregonensis,* blue) found at Chipps Island in fall 2012. Boxplot of dietary proportions for the different sources availble depicts 25, 75 and 95% credibility intervals.

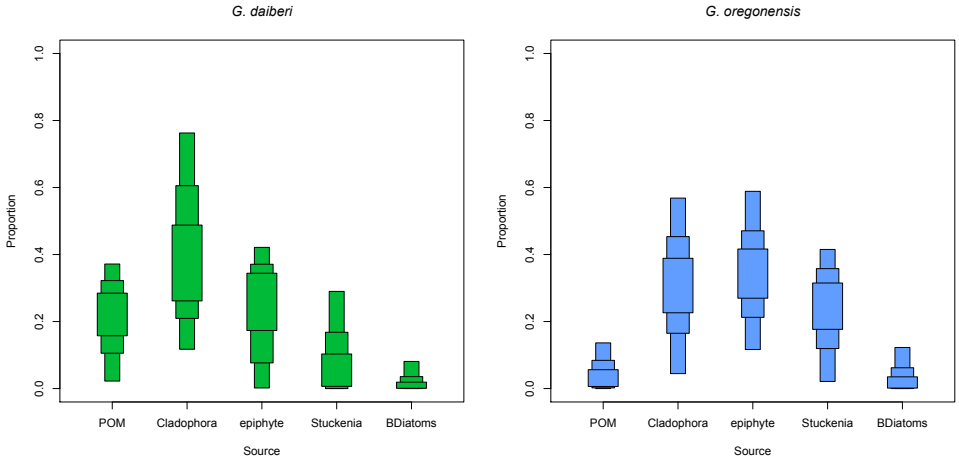



Figure 26: **WI -** Output of the SIAR mixing model for invertebrate consumers (*Gammarus daiberi*, green; *Gnorimosphaeroma oregonensis,* blue) found at Winter Island in fall 2012. Boxplot of dietary proportions for the different sources availble depicts 25, 75 and 95% credibility intervals.

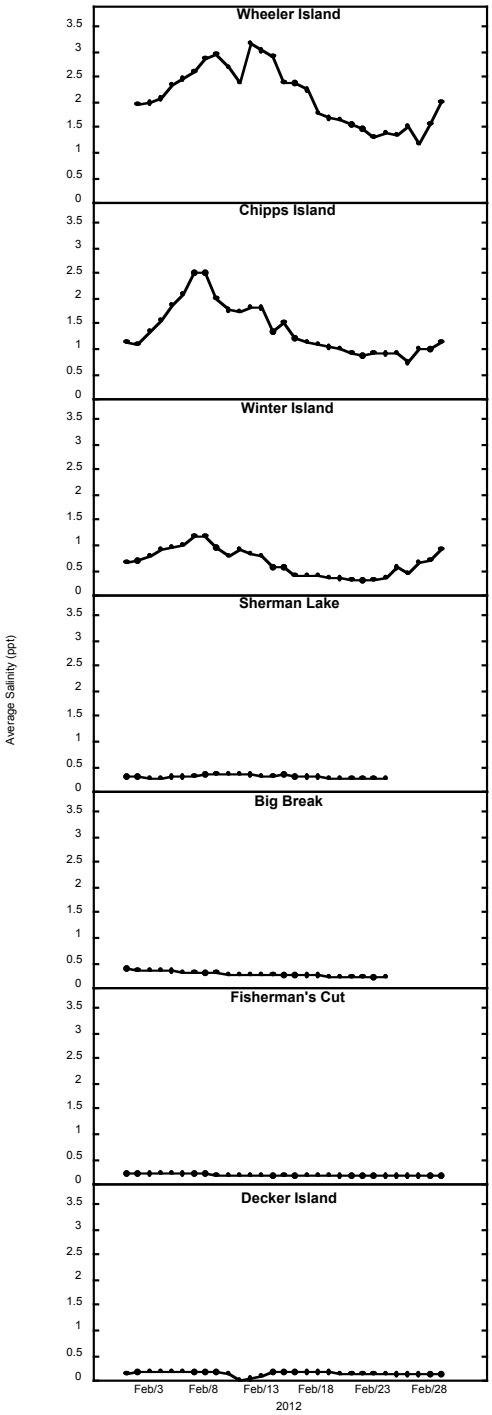



Figure 27. Daily averaged salinity concentrations (ppt) for all sites in February 2012. Salinity at Ryer Island was not measured due to sensor damage.

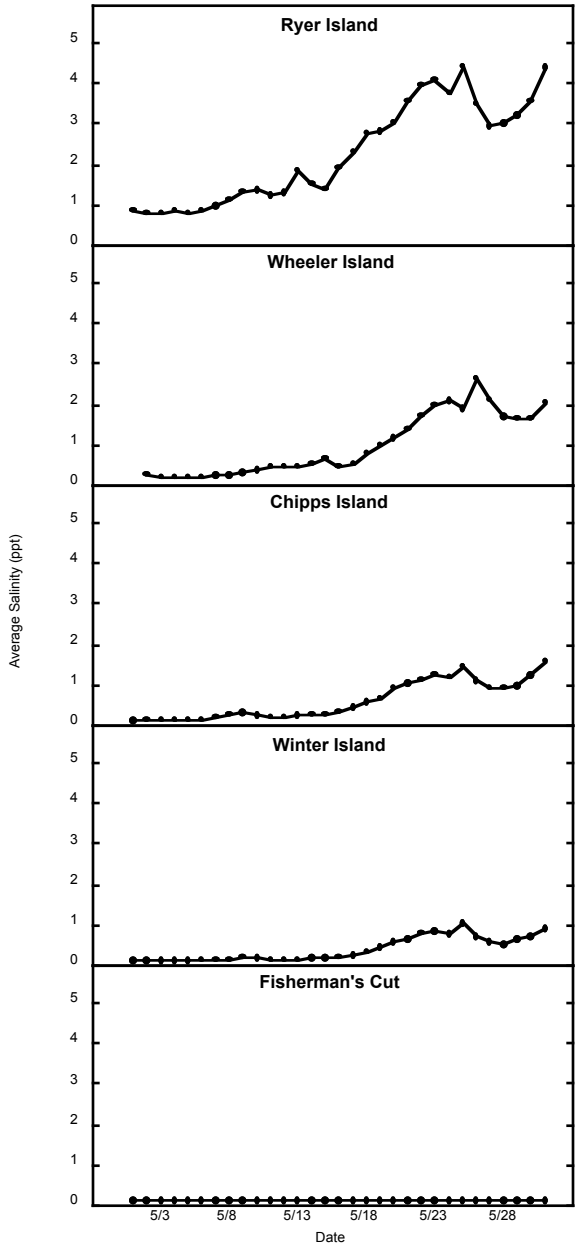



Figure 28. Daily averaged salinity concentrations (ppt) for all sites in May 2012. Sherman Lake, Big Break, and Fisherman's Cut were not measured due to sensor damage.

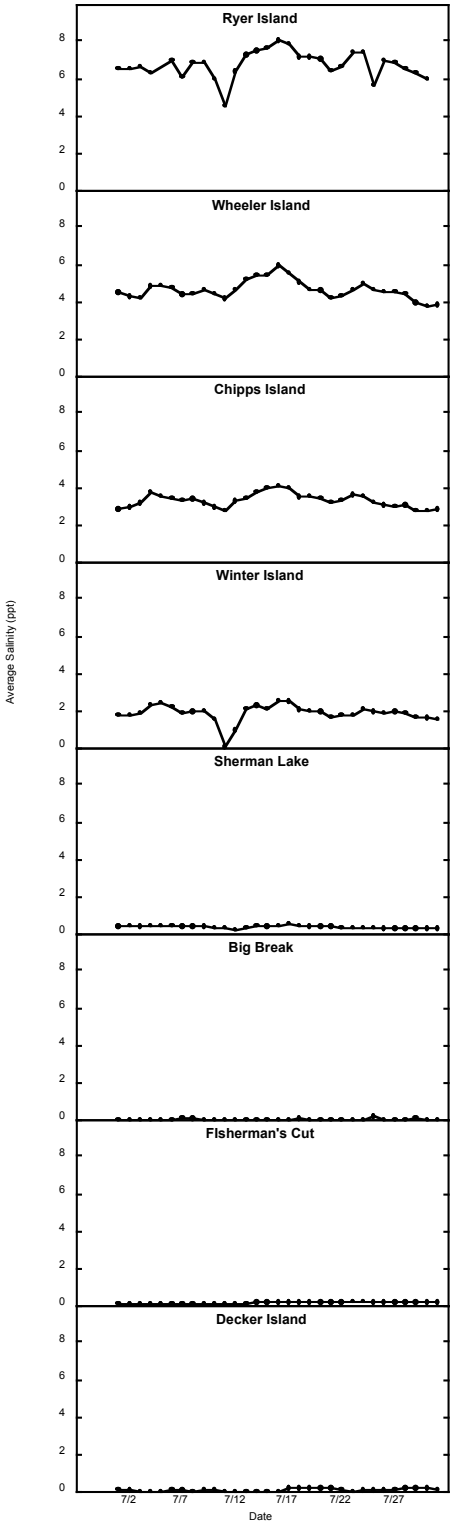



Figure 29. Daily averaged salinity concentrations (ppt) for all sites in July 2012.

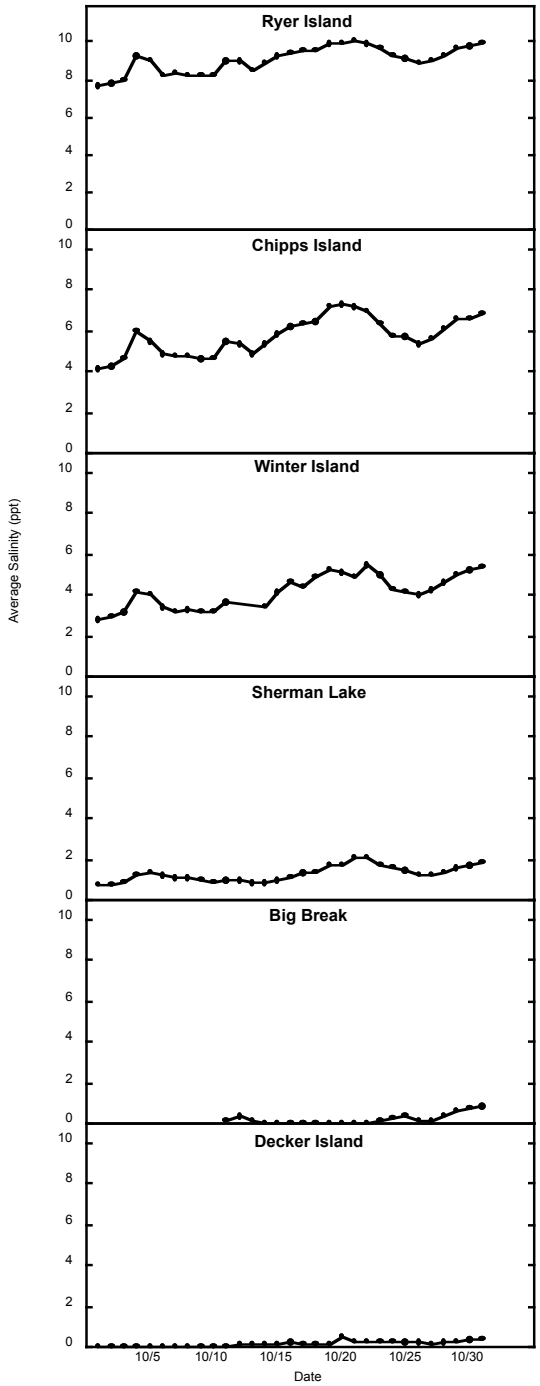



Figure 30. Daily averaged salinity concentrations (ppt) for all sites in October 2012. Wheeler Island anad Fisherman's Cut were not measured due to sensor damage.

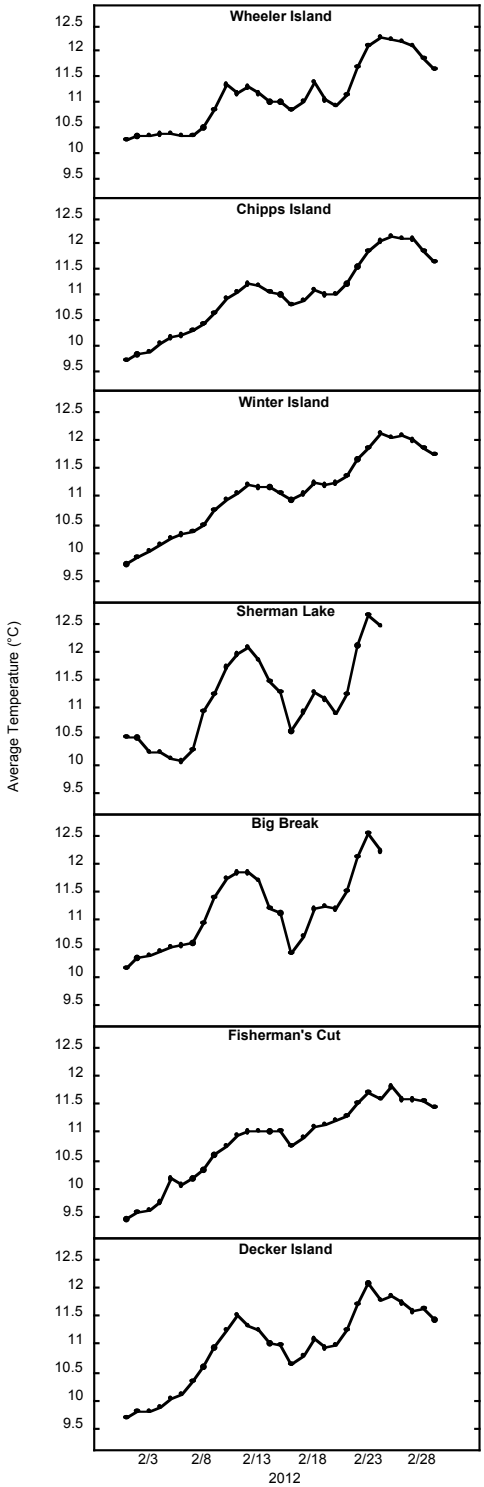



Figure 31. Daily averaged temperature levels (°C) for all within-bed sites in February 2012. Rye Island was not measured due to sensor damage.

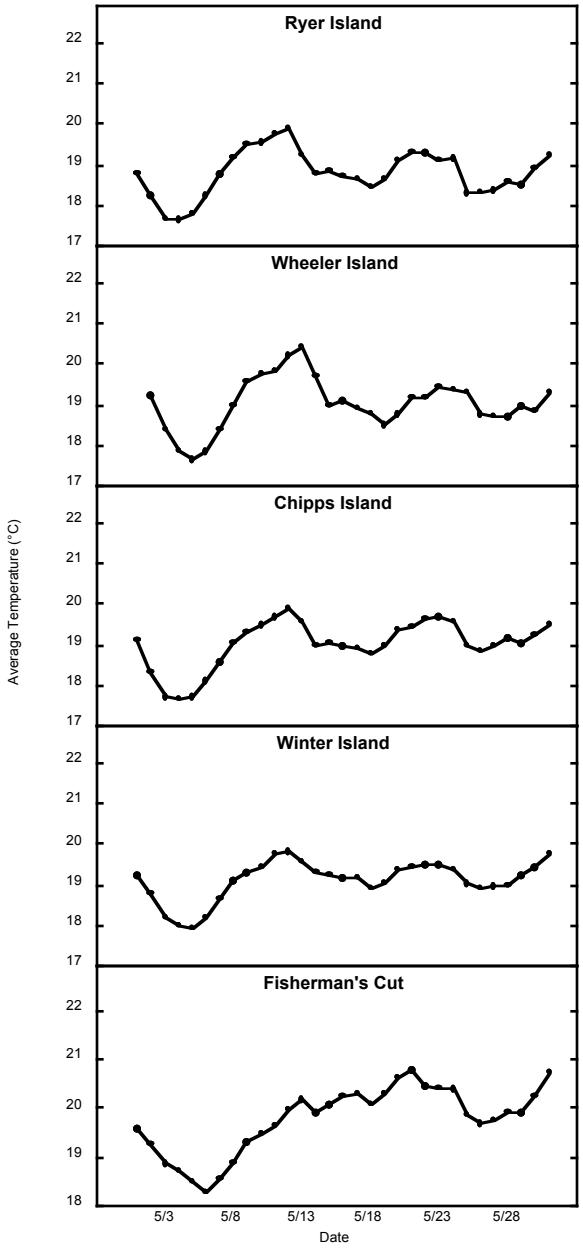



Figure 32. Daily averaged temperature levels (°C) for all within-bed sites in May 2012. Sherman Lake, Big Break, and Decker Island were not measured due to sensor damage.

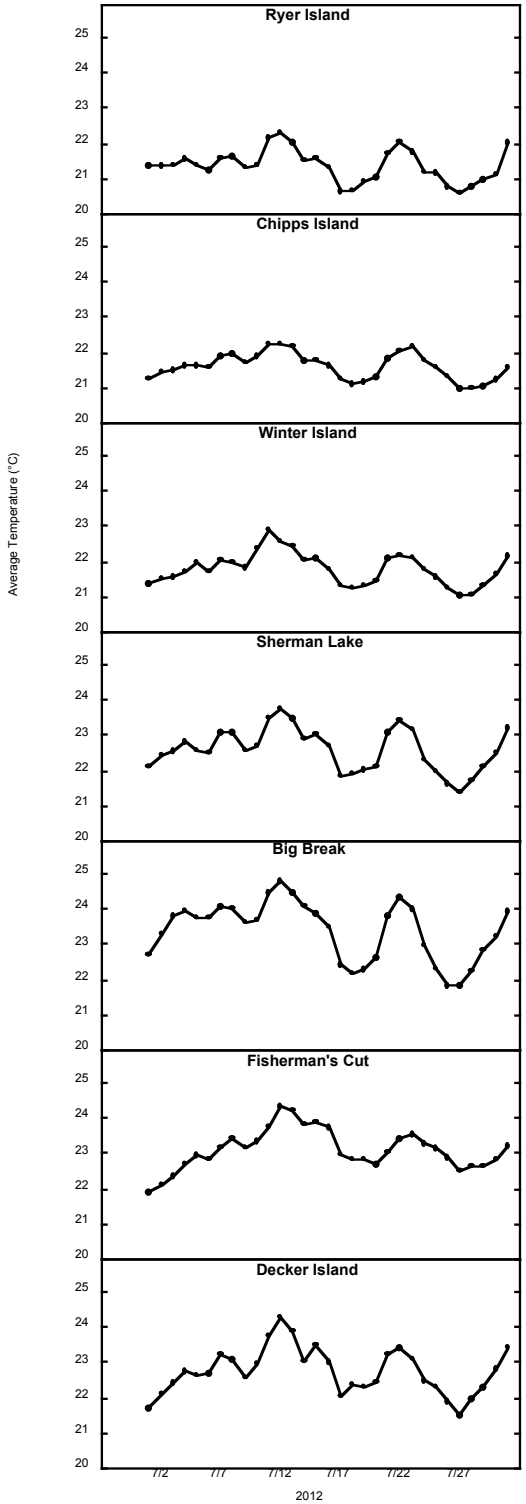



Figure 33. Daily averaged temperature levels (°C) for all within-bed sites in July 2012.

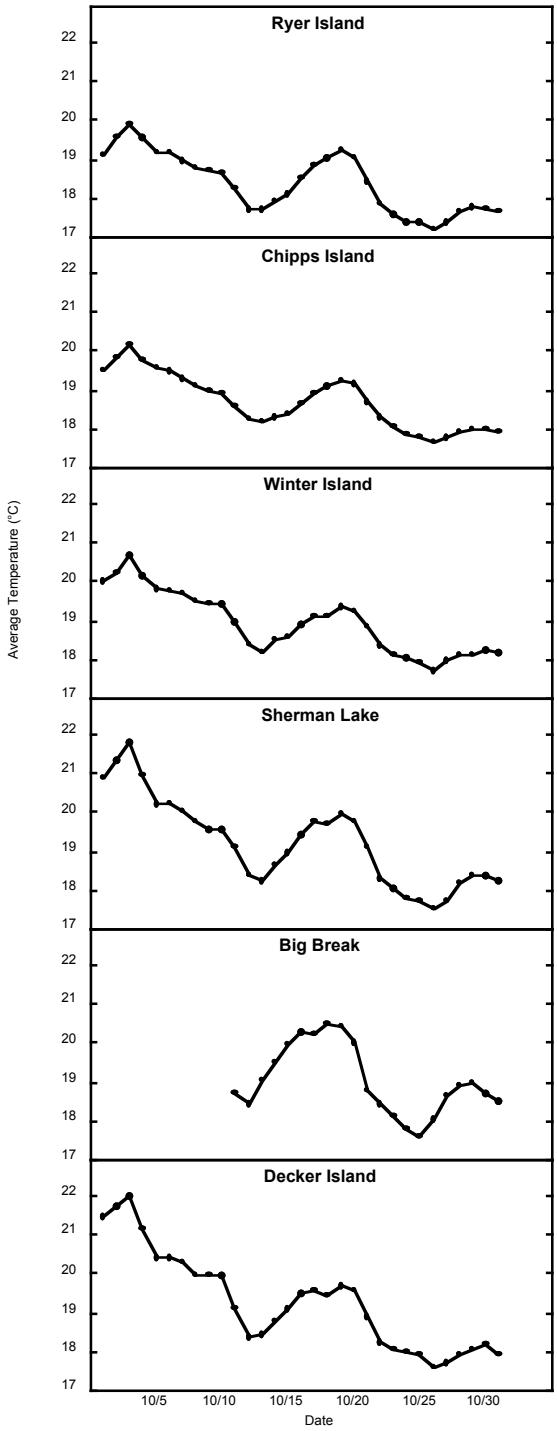



Figure 34. Daily averaged temperature levels (°C) for all within-bed sites in October 2012. Wheeler Island and Fisherman's Cut were not measured due to sensor damage.

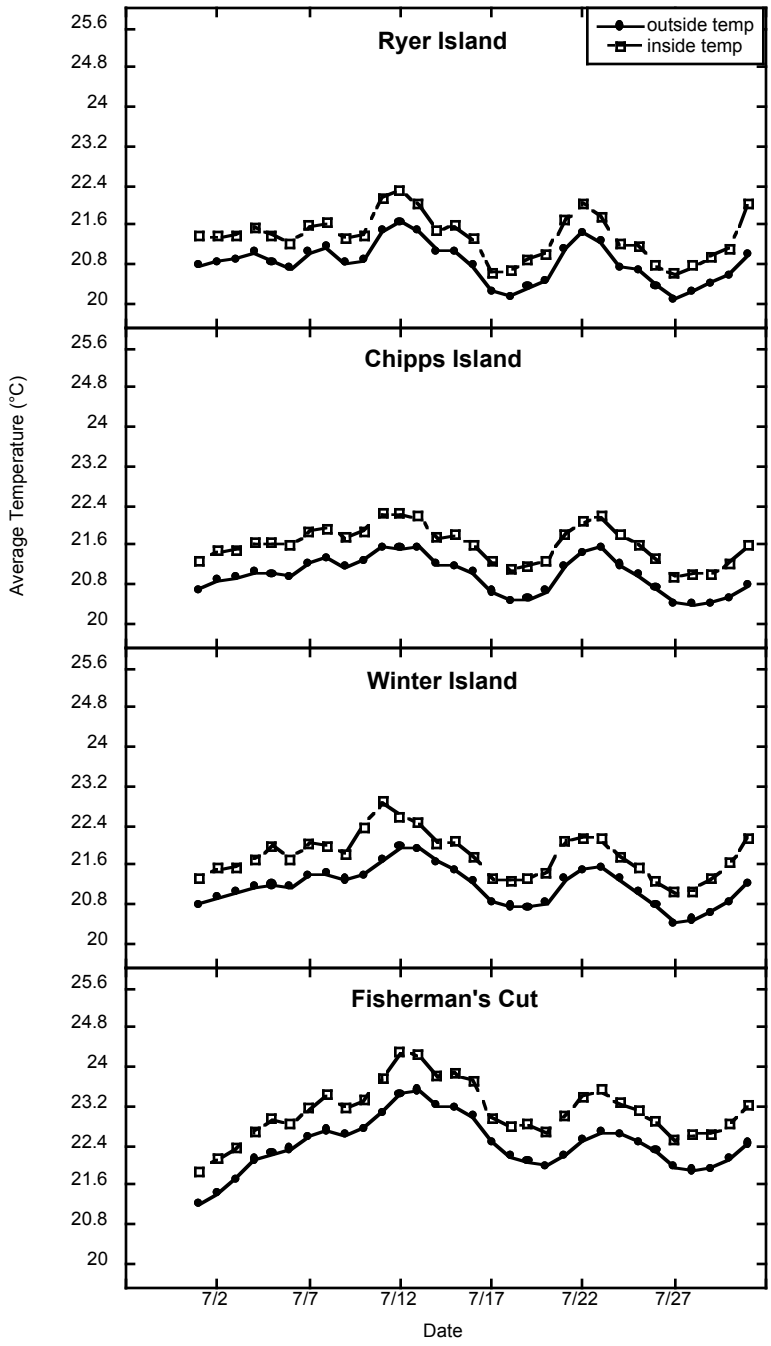



Figure 35. Daily averaged temperature levels (°C) for inside and outside SAV bed locations in July 2012. The only sites included contained complete data from both data loggers for the allotted time period.

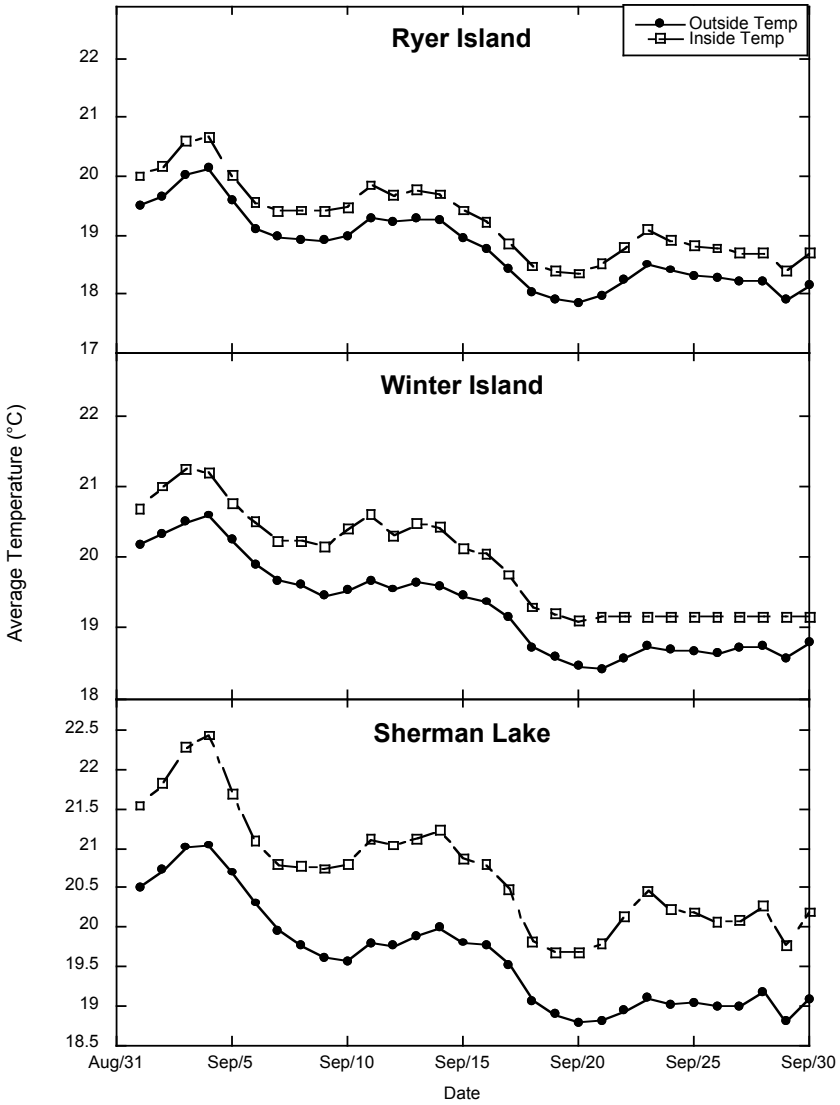



Figure 36. Daily averaged temperature levels (°C) for inside and outside SAV bed locations in September 2012. The only sites included contained complete data from both data loggers for the allotted time period.

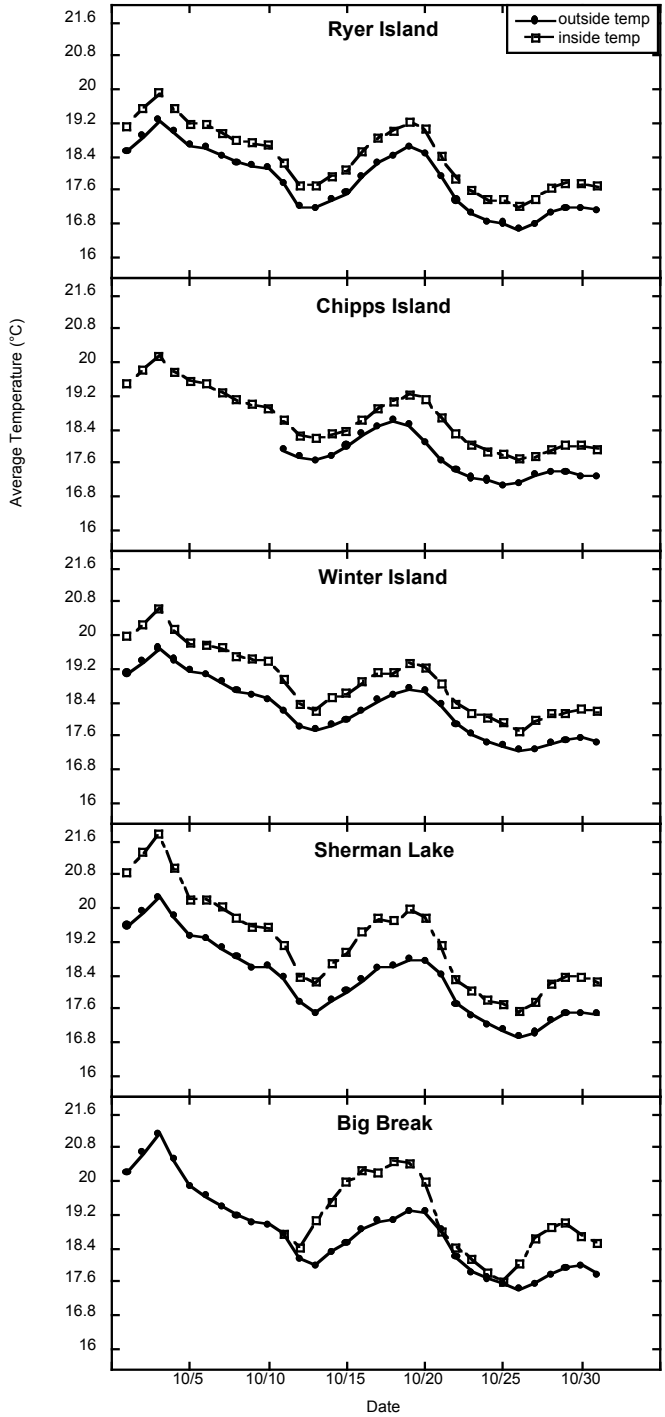



Figure 37. Daily averaged temperature levels (°C) for inside and outside SAV bed locations in October 2012. The only sites included contained complete data from both data loggers for the allotted time period.

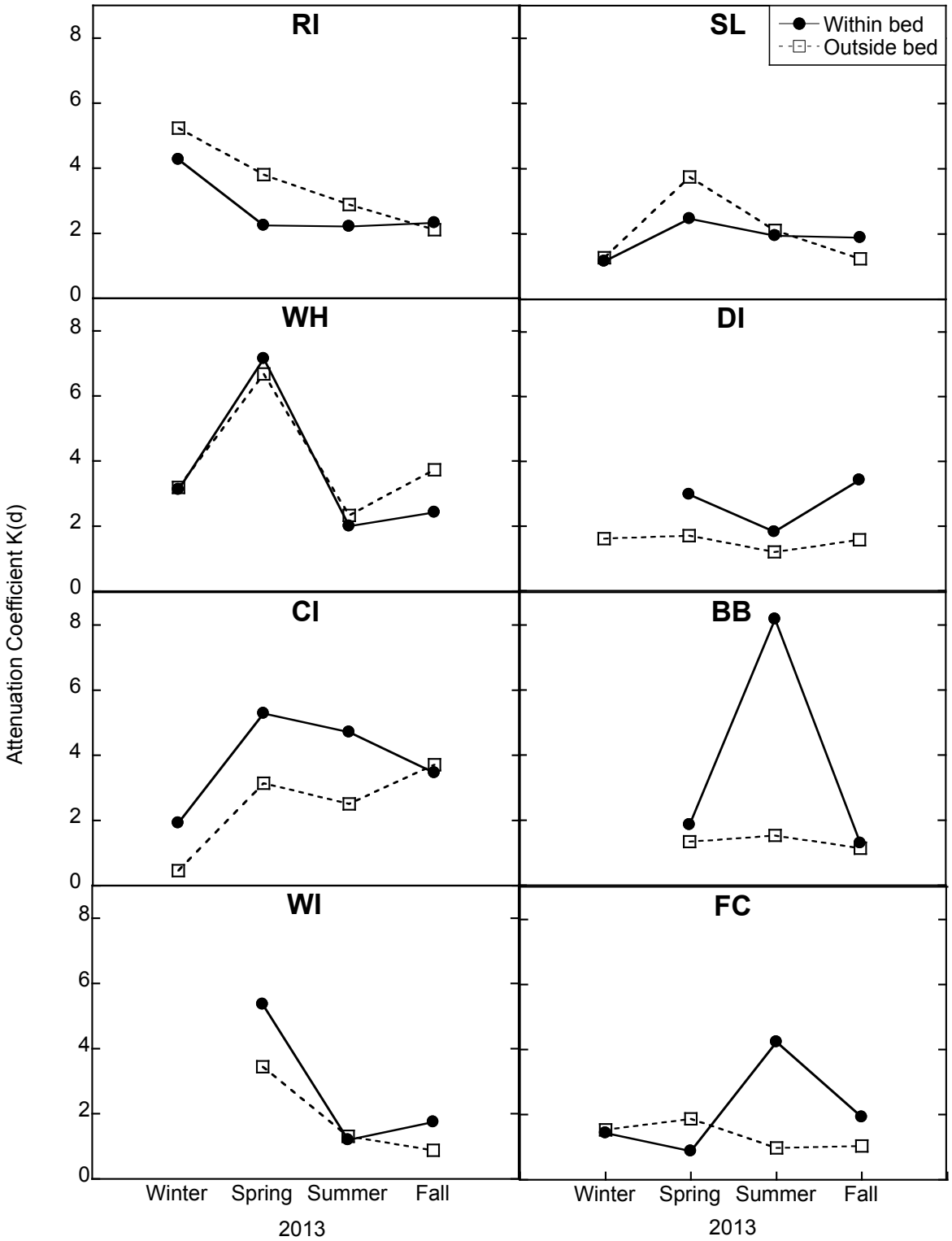



Figure 38. Light attenuation coefficients K(d) by site, measured quarterly in 2013. Higher K(d) values indicate less light penetration through the water column.

## PROJECT-WIDE STATUS

ACHIEVED OBJECTIVES, FINDINGS, AND CONTRIBUTIONS: THE PROJECT IS NOW COMPLETE.

PROBLEMS OR DELAYS ENCOUNTERED: SEE ABOVE FOR ADJUSTMENTS TO SAMPLING PLANS BASED ON PRELIMINARY SAMPLING AND PROCESSING.

DELIVERABLES (PLEASE ATTACH ALL PUBLICATIONS LISTED HERE): NONE YET.

PERSONNEL CHANGES: NONE

CONTRACT MODIFICATIONS: NONE

NOTES/OTHER: NONE

## REFERENCES

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## APPENDICES

### Appendix I: Overall abundances of invertebrates throughout the project timeline

Table 1. Mean abundance of invertebrate species per sample collected from SAV at all 8 sites in the Suisun Bay and western Delta between October 2011 and October 2012. NS indicates no sample was available for that time period. N = a species that is native to the study region, I = a species that was introduced. RI = Ryer Island, WH =Wheeler, CI = Chipps Island, WI = Winter Island, SL= Sherman Lake, DI = Decker Island, BB = Big Break, FC=Fisherman's Cut.

| | Species | Type | Status | RI (NS) | WH (NS) | CI | WI | SL (NS) | DI | BB | FC (NS) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fall 2011 | *Gammarus daiberi* | Amphipod | I | | | 24.4 | 8.3 | | 0 | 0 | |
| | *Hyalella azteca* | Amphipod | N | | | 0 | 0 | | 6.2 | 23.2 | |
| | *Americorophium spinicorne* | Amphipod | I | | | 0.05 | 0 | | 0 | 0.2 | |
| | *Gnorimosphaeroma oregonensis* | Isopod | N | | | 5.0 | 0.9 | | 0 | 0 | |
| | *Physa* sp. | Gastropod | I | | | 0 | 0 | | 0.9 | 0.8 | |
| | *Gyraulus circumstriatus* | Gastropod | I | | | 0.2 | 0 | | 0.9 | 0 | |
| | *Chironomus* sp. | Midge fly | | | | 0.05 | 25.7 | | 2.05 | 12.0 | |
| | Dragonfly larvae | Dragon fly | | | | 0 | 0.05 | | 0 | 0 | |
| | Hydrachnidiae (family) | Water mite | | | | 0 | 0 | | 0.05 | 0 | |
| | *Schmidtea* sp. | Flat worm | | | | 0 | 0 | | 0.4 | 0.1 | |
| | Limpet | Limpet | | | | 0 | 0 | | 0.1 | 0 | |
| Winter 2012 | Species | Type | Status | RI (NS) | WH (NS) | CI (NS) | WI (NS) | SL | DI | BB | FC |
| | *Ampithoe valida* | Amphipod | I | | | | | 0.1 | 0.2 | 0.3 | 0 |
| | *Gnorimosphaeroma oregonensis* | Isopod | N | | | | | 0.4 | 2.7 | 0.5 | 0.1 |
| | *Caecidotea* sp. | Isopod | N | | | | | 1.9 | 2.3 | 0.5 | 0.8 |
| | *Physa* sp. | Gastropod | I | | | | | 3.9 | 10.0 | 25.2 | 5.8 |
| | *Helisoma anceps* | Gastropod | N | | | | | 0.9 | 13.5 | 2.2 | 1.3 |
| | *Hydrobia* sp. | Gastropod | I | | | | | 0.2 | 6.0 | 1.3 | 0.6 |
| | *Chironomus* sp. | Midge fly | | | | | | 0.3 | 0 | 0.1 | 0 |
| | Limpet | Limpet | | | | | | 0 | 0.3 | 0.3 | 0 |
| Spring 2012 | Species | Type | Status | RI | WH | CI | WI | SL | DI | BB | FC |
| | *Gammarus daiberi* | Amphipod | I | 0 | 0 | 0.4 | 1.4 | 0 | 0 | 0 | 0.2 |
| | *Hyalella azteca* | Amphipod | N | 0 | 0 | 1.8 | 0 | 0.9 | 12.0 | 0.8 | 4.6 |
| | *Americorophium spinicorne* | Amphipod | I | 0 | 0 | 0 | 2.4 | 0 | 0.3 | 0 | 3.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Gnorimosphaeroma oregonensis* | Isopod | N | 0 | 0 | 2.4 | 0.2 | 0 | 0 | 0 | 0 |
| | *Caecidotea* sp. | Isopod | N | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3 |
| | *Physa* sp. | Gastropod | I | 0 | 0 | 0 | 0 | 2.7 | 3.3 | 0.1 | 39.4 |
| | *Gyraulus circumstriatus* | Gastropod | I | 0 | 0 | 0 | 0 | 1.4 | 3.7 | 0.6 | 18.9 |
| | *Helisoma anceps* | Gastropod | N | 0 | 0 | 0 | 0 | 0.4 | 0 | 0 | 0.6 |
| | *Chironomus* sp. | Midge fly | | 0 | 0 | 0 | 0.1 | 0.7 | 20.7 | 0.8 | 8.8 |
| | Dragon fly larvae | Dragon fly | | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0.3 |
| | Hydrachnidiae (family) | Water mite | | 0 | 0 | 0 | 0 | 0 | 0.3 | 0 | 0.4 |
| | *Schmidtea* sp. | Flat worm | | 0 | 0 | 0 | 0 | 0.4 | 0 | 0 | 0.3 |
| | Limpet | Limpet | | 0 | 0 | 0 | 0 | 0 | 1.0 | 0 | 12.6 |
| **Summer 2012** | **Species** | **Type** | **Status** | **RI** | **WH** | **CI** | **WI** | **SL** | **DI** | **BB** | **FC** |
| | *Gammarus daiberi* | Amphipod | I | 0.3 | 0 | 0.1 | 0 | 0.2 | 0 | 0 | 0 |
| | *Hyalella azteca* | Amphipod | N | 0 | 0 | 0 | 0 | 0.6 | 5.2 | 0.7 | 5 |
| | *Americorophium spinicorne* | Amphipod | I | 0 | 0 | 0 | 0 | 0.1 | 0.1 | 0 | 0 |
| | *Ampithoe valida* | Amphipod | I | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Gnorimosphaeroma oregonensis* | Isopod | N | 1.4 | 1 | 1.1 | 0.2 | 0 | 0 | 0 | 0 |
| | *Physa* sp. | Gastropod | I | 0 | 0 | 0 | 0 | 1.5 | 1.1 | 3.8 | 28.4 |
| | *Gyraulus circumstriatus* | Gastropod | I | 0 | 0 | 0 | 0 | 0.4 | 1 | 2.6 | 1.8 |
| | *Helisoma anceps* | Gastropod | N | 0 | 0 | 0 | 0 | 0.3 | 0 | 0 | 0.2 |
| | *Hydrobia* sp. | Gastropod | I | 0 | 0 | 0 | 0.7 | 0 | 0 | 0 | 0 |
| | *Fluminicola* sp. | Gastropod | | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0 |
| | *Pancolus californiensis* | Tanaid | N | 0 | 0.5 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| | *Chironomus* sp. | Midge fly | | 0 | 0.5 | 0.7 | 4.6 | 8.4 | 2.7 | 2.0 | 0.6 |
| | Dragon fly larvae | Dragon fly | | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.1 | 0 |
| | Hydrachnidiae (family) | Water mite | | 0 | 0 | 0 | 0 | 0.2 | 0 | 0.6 | 0 |
| | *Schmidtea* sp. | Flat worm | | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 |
| **Fall 2012** | **Species** | **Type** | **Status** | **RI** | **WH** | **CI** | **WI** | **SL** (NS) | **DI** (NS) | **BB** (NS) | **FC** (NS) |
| | *Gammarus daiberi* | Amphipod | I | 0 | 45.8 | 17.1 | 119.4 | | | | |
| | *Ampithoe valida* | Amphipod | I | 42.1 | 43.1 | 10.8 | 0 | | | | |
| | *Gnorimosphaeroma oregonensis* | Isopod | N | 2.1 | 19.3 | 0.7 | 1.9 | | | | |
| | *Synidotea laticauda* | Isopod | I | 0.1 | 0.4 | 0 | 0 | | | | |
| | *Hydrobia* sp. | Gastropod | I | 0 | 0.9 | 0 | 0 | | | | |
| | *Palaemon macrodactylus* | Shrimp | N | 0 | 0 | 0 | 0.3 | | | | |
| | *Pancolus californiensis* | Tanaid | N | 0.3 | 0.7 | 13.3 | 0.3 | | | | |
| | *Chironomus* sp. | Midge fly | | 0 | 0 | 0 | 0.2 | | | | |
| | Hydrachnidiae (family) | Water mite | | 0 | 0 | 14.1 | 0 | | | | |

**Appendix II: Spatial variation in elemental and isotopic composition in the 6 most comonly found plant taxa across all dates**

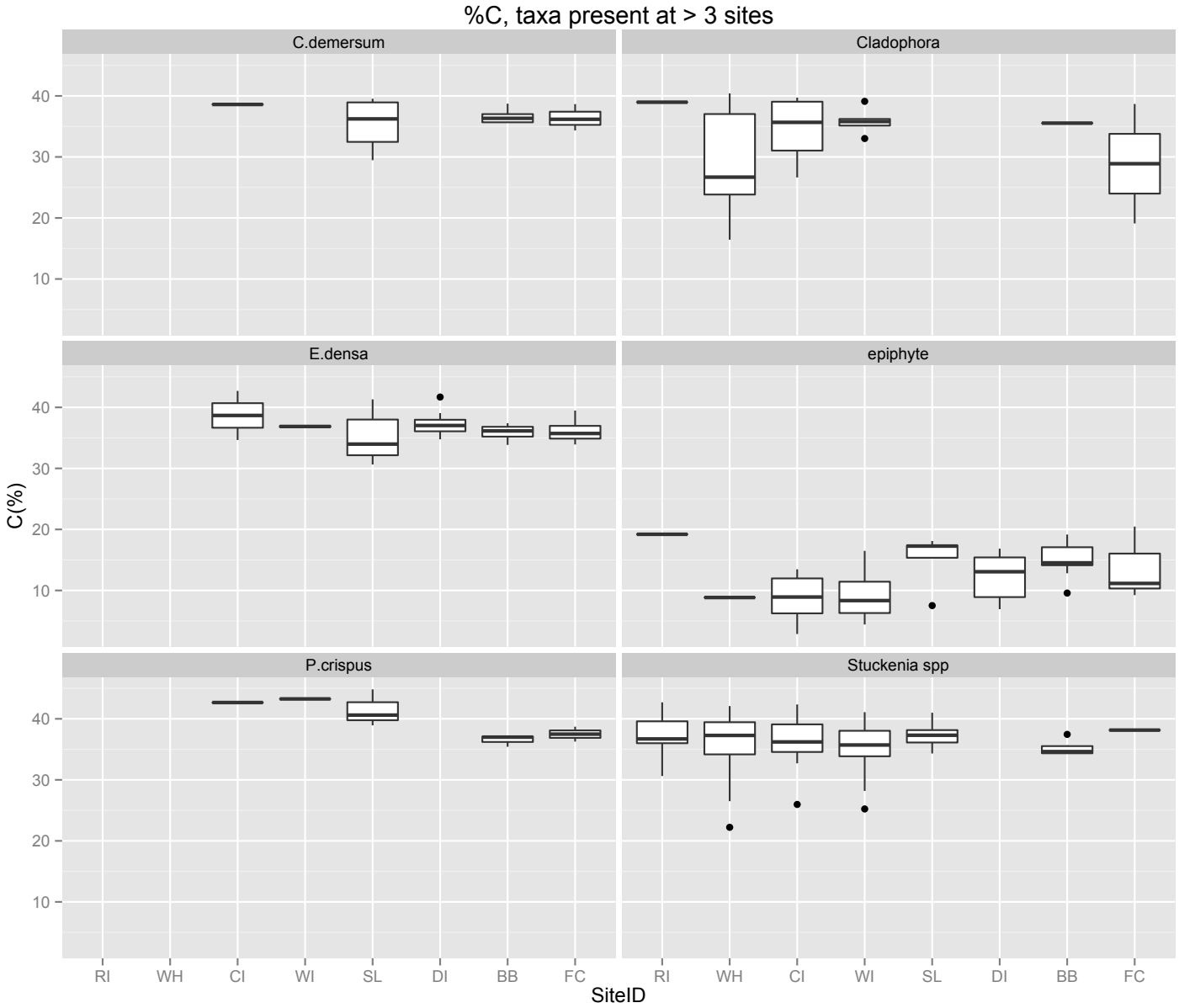


Figure IIA. Carbon percent composition variations across sampling sites for the 6 most commonly found plant taxa. Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

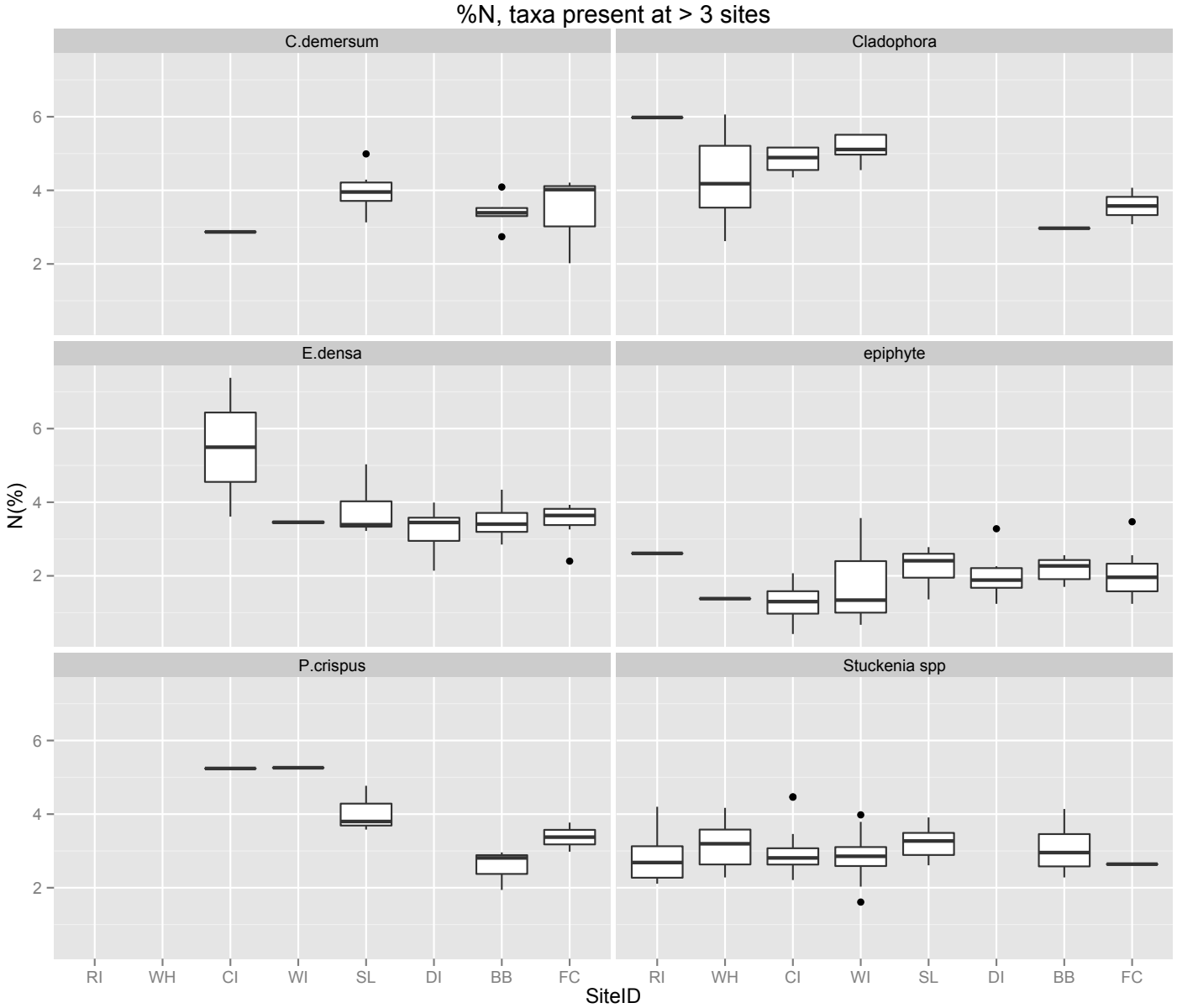


Figure IIB. Nitrogen percent composition variations across sampling sites for the 6 most commonly found plant taxa. Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

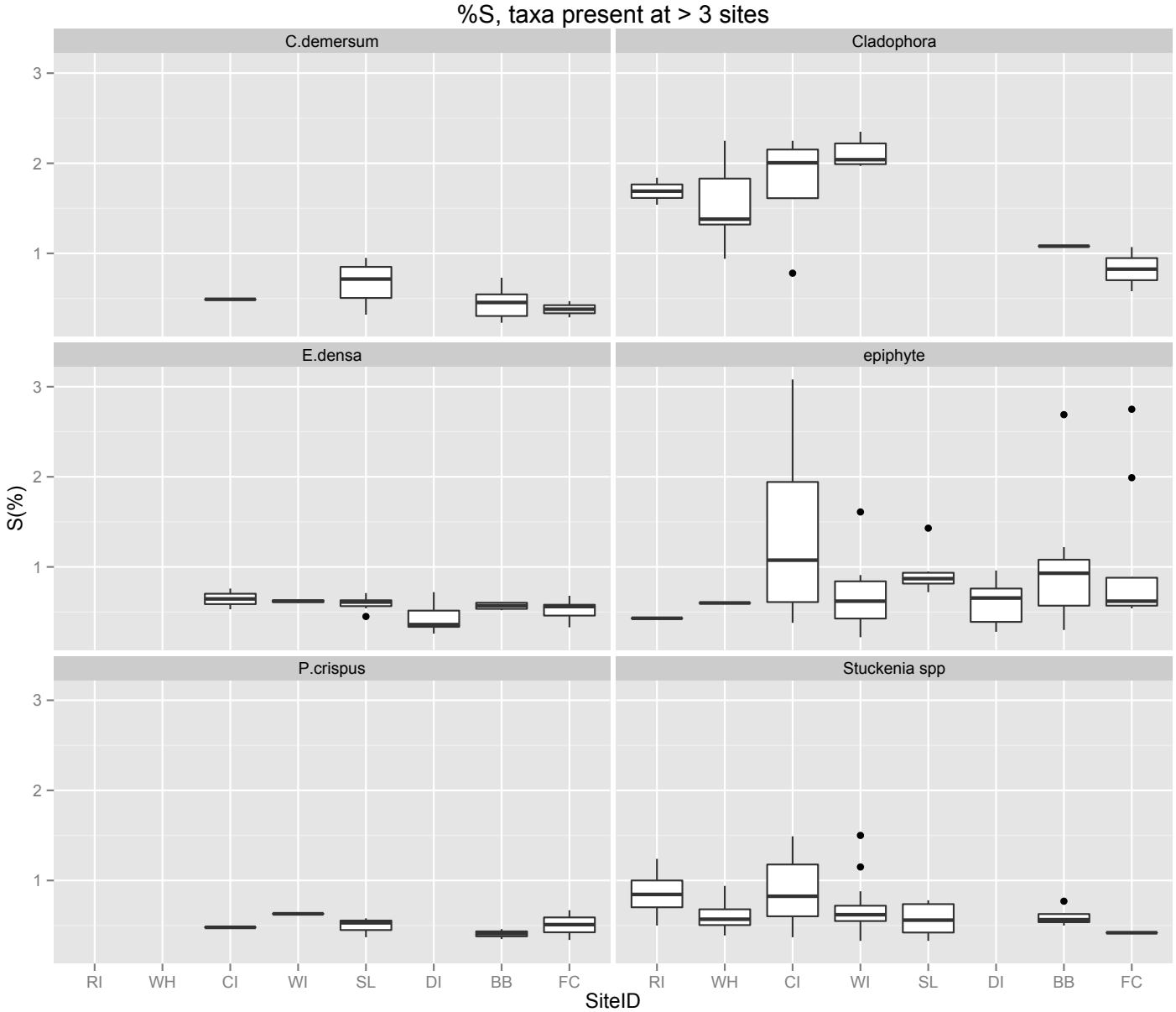


Figure IIC. Sulphur percent composition variations across sampling sites for the 6 most commonly found plant taxa. Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

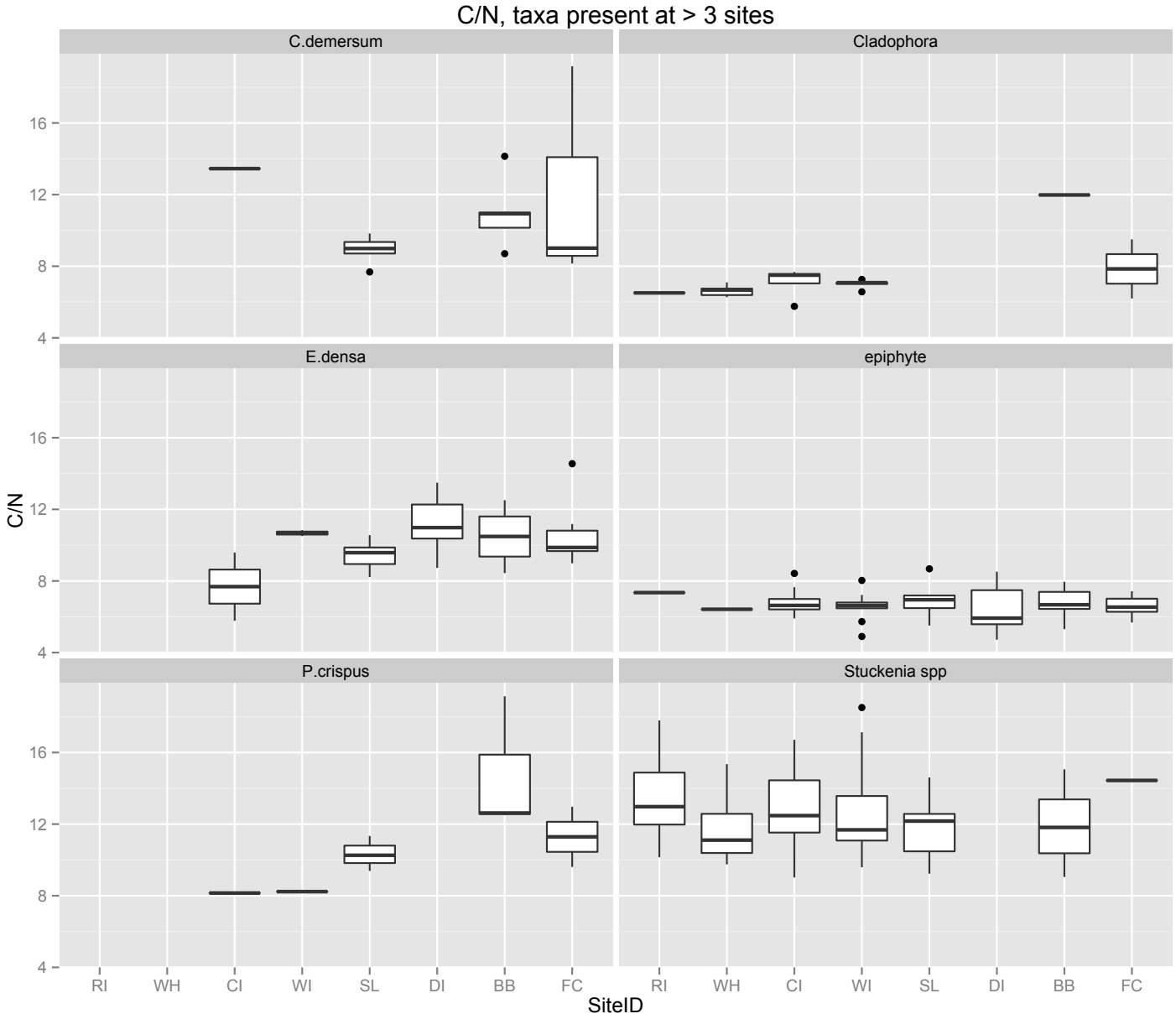


Figure IID. C/N ratio variations across sampling sites for the 6 most commonly found plant taxa. Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

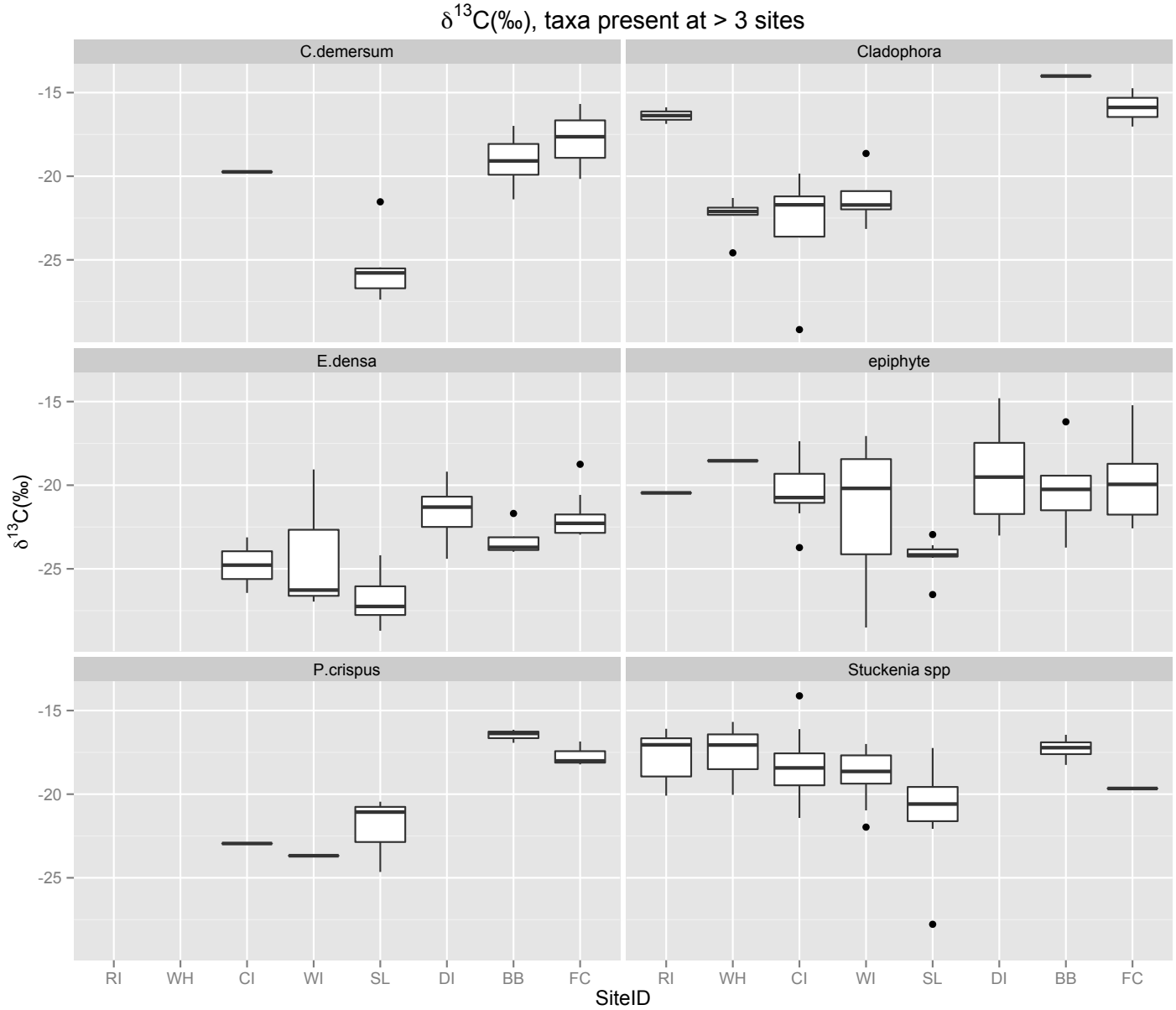


Figure IIE. $\delta^{13}C$ variations across sampling sites for the 6 most commonly found plant taxa. Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

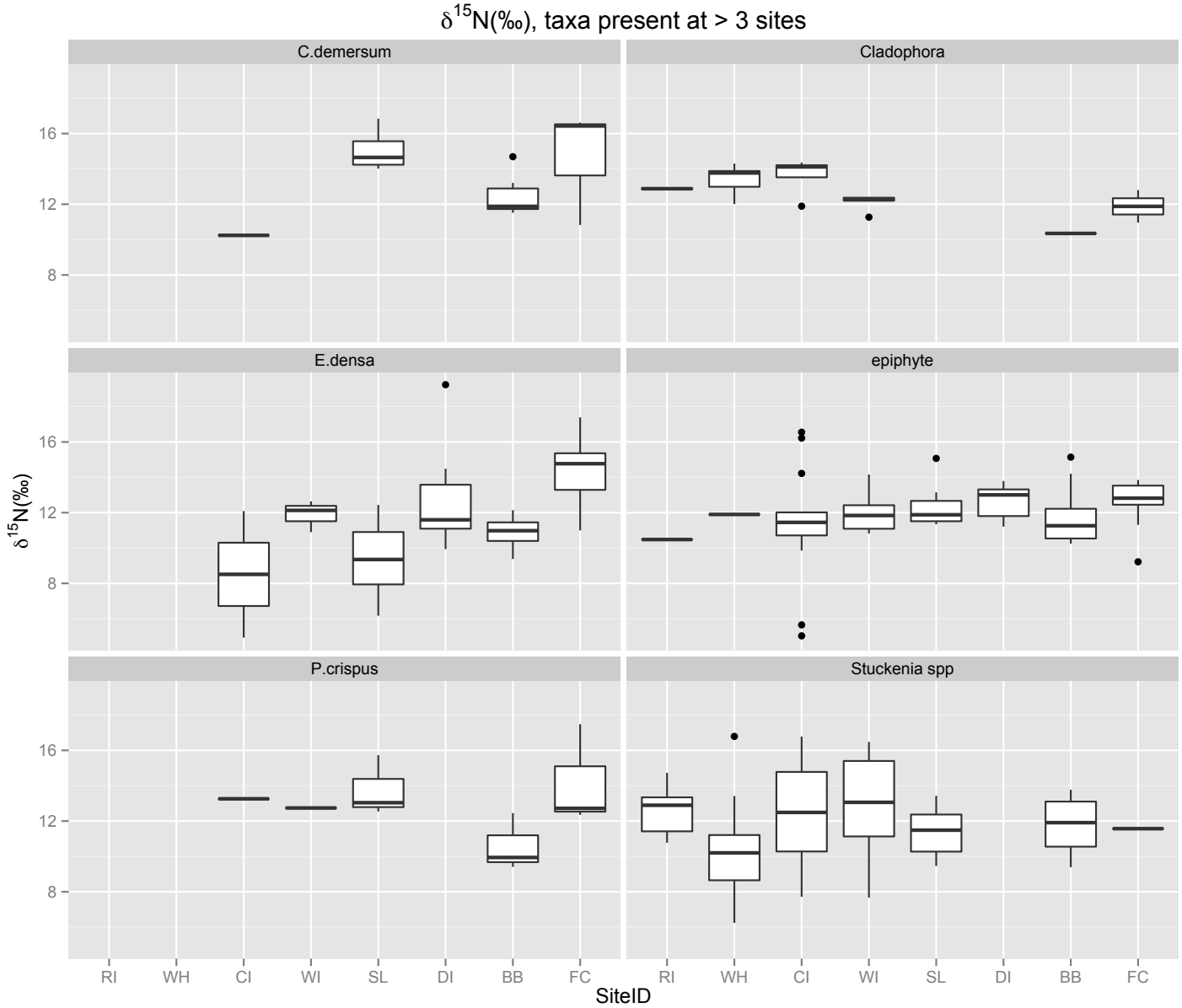


Figure IIF. $\delta^{15}N$ variations across sampling sites for the 6 most commonly found plant taxa. Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

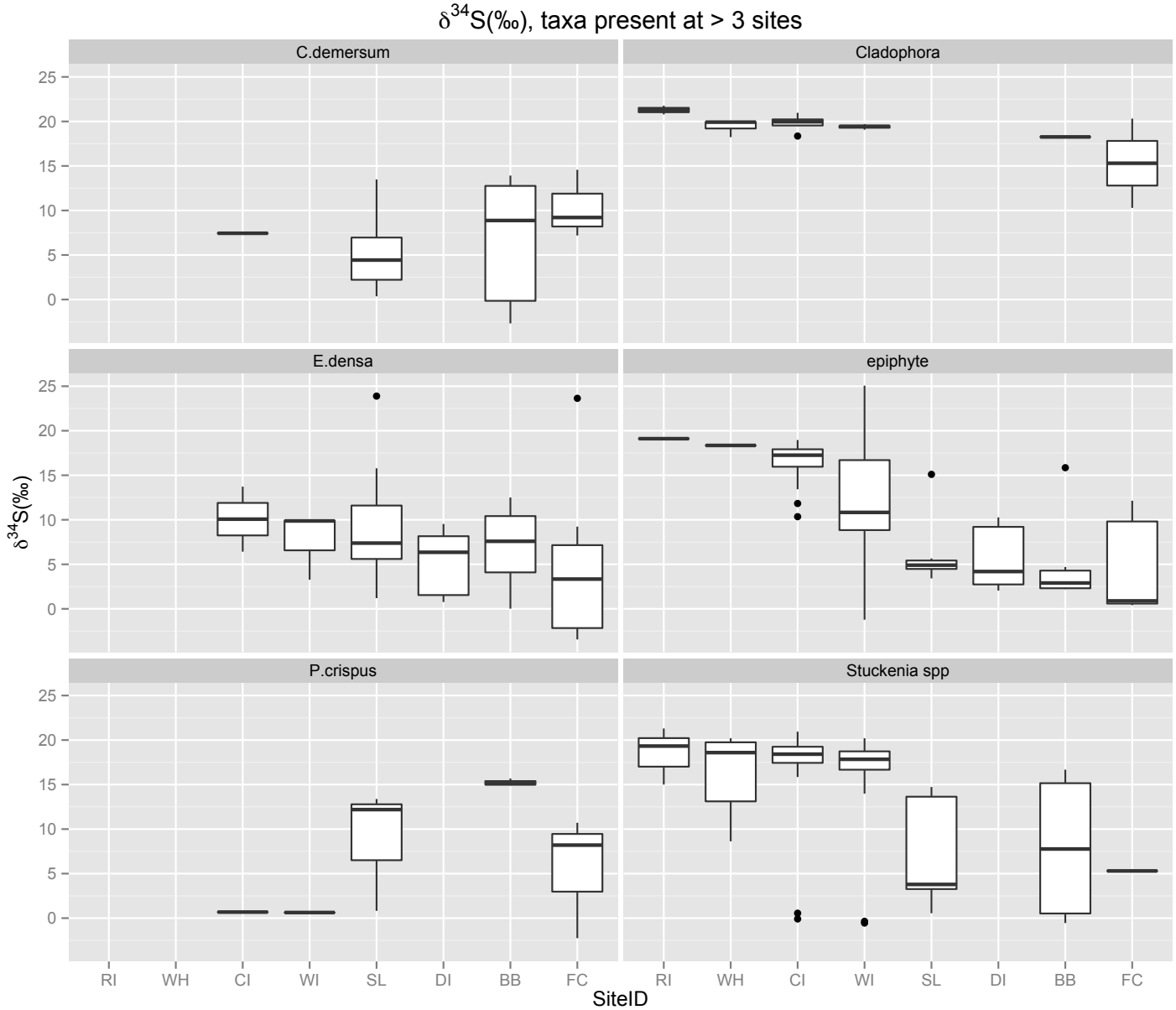


Figure IIG. $\delta^{34}S$ variations across sampling sites for the 6 most commonly found plant taxa. Ryer Island (RI), Wheeler Island (WH), Chipps Island (CI), Winter Island (WI), Sherman Lake (SL), Decker Island (DI), Big Break (BB), Fisherman's Cut (FC).

**Budget Summary**

Tasks 1&2 (SF State Projects 50223000 and 50223001)

| Expense | | Amount invoiced (current fiscal year) | Amount invoiced to date (all years) |
|---|---|---|---|
| Salaries and Wages | | 8,656.73 | 49,478.99 |
| Employee Benefits | | 1188.82 | 6,260.52 |
| Equipment & Facilities | | | |
| Supplies, Materials & Services | | 13,352.84 | 39,803.73 |
| Travel | | -137.18 | 1,559.56 |
| Stipends | | 20,640.00 | 38,640.00 |
| Indirect Costs | | 5,746.80 | 24,257.20 |
| | | | |
| Totals | | 49,448.01 | 160,000.00 |