Influences of water quality and submerged aquatic vegetation on largemouth bass distribution, abundance, diet composition and predation on Delta smelt in the Sacramento-San Joaquin Delta

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INFLUENCES OF WATER QUALITY AND SUBMERGED AQUATIC VEGETATION ON LARGEMOUTH BASS DISTRIBUTION, ABUNDANCE, DIET COMPOSITION AND PREDATION ON DELTA SMELT IN THE SACRAMENTO-SAN JOAQUIN DELTA

LIST OF DELIVERABLES AND TABLE OF CONTENTS

This is a final report to the United States Bureau of Reclamation (USBR) for Agreement R10AC20090. With this report and its attachments, final contract deliverables are provided to USBR.

Task 1 deliverables included as supplementary files:

- Draft manuscript prepared for submission to *Transactions of American Fisheries Society*: Invasion of Brazilian waterweed *Egeria densa* facilitates expansion of an estuarine population of largemouth bass *Micropterus salmoides.*

- Draft manuscript prepared for submission to *Environmental Biology of Fishes:* Brazilian waterweed *Egeria densa* influences condition and diet of largemouth bass *Micropterus salmoides* in the Sacramento-San Joaquin Delta.

- Published article in *Environmental Biology of Fishes:* Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass.

Task 2 deliverables included as supplementary files:

- Spring 2012 oral presentation to the Interagency Ecological Program Workshop: “Genetic detection of predation larval delta smelt.” Presenter: Brian Schreier, California Department of Water Resources.

- October 2012 oral presentation at the Delta Science Council Conference, Sacramento, CA. “Fish communities of the North Delta.” Presenter: Denise De Carion, University of California, Davis.

Task 3. Influence of the SAV species and biomass on invertebrate community composition and biomass

Task 3 deliverables included as supplementary files:

- Draft manuscript prepared for submission to peer-reviewed journal: The effect of submerged aquatic vegetation on invertebrate communities and juvenile largemouth bass (*Micropterus salmoides*) growth and diet
- October 2012 poster presentation at the Delta Science Council Conference, Sacramento, CA. “Vegetation-associated macroinvertebrates communities in the Sacramento-San Joaquin Delta.”

Other deliverables included as supplementary files:

- 2008-2010 Nearshore Survey Database Metadata Report for Sacramento-San Joaquin Electrofishing and Submerged Aquatic Vegetation Surveys conducted by UC Davis Departments of Environmental Science & Policy (Sih Laboratory) and Wildlife, Fish, and Conservation Biology (Moyle Laboratory).
- Largemouth Bass Diet Analysis: Identification of Ingested Fishes of the Sacramento-San Joaquin Delta using Cliethra. Prepared by Denise De Carion, University of California, Davis.
- 2008-2010 Sacramento-San Joaquin Nearshore Survey Database (MS Access file).

EXECUTIVE SUMMARY

Largemouth bass (LMB, *Micropterus salmoides*) is an introduced predator of the Sacramento-San Joaquin Delta (Delta) that, despite a long-term presence, has demonstrated a dramatic increase in abundance only in recent decades. When introduced in other systems, LMB have been known to cause significant changes to the existing trophic structure. As predation by introduced predators has been identified as a potential driver of declining abundance of several pelagic fishes in the Delta (Pelagic Organism Decline, or POD), an understanding of the role of LMB as a major piscivore in the system is critical to predator management. The observed increase in the LMB population appears to be associated with the substantial increase in submerged aquatic vegetation (SAV) - in particular, the spread of the invasive Brazilian waterweed, *Egeria densa* in the 1990s. Until the present study, however, quantitative work to understand the relationship between *Egeria* and LMB had not been done.

To address these knowledge gaps, the Interagency Ecological Program (IEP) provided funding (Contract #4600008137 Task 1) in 2008 to a team of researchers at the Departments of Environmental Science & Policy and Wildlife, Fish & Conservation Biology at the University of California, Davis (UCD). Additional IEP funding was provided in 2010 through the United States Bureau of Reclamation (USBR, contract #R10AC20090). The objectives of this multi-year research effort were to: (1) Assess LMB abundance, size distribution, and diet composition with respect to SAV density and water quality in the Delta; (2) Describe LMB predation rates on delta smelt (*Hypomesus transpacificus*, an endemic, listed species and part of the POD) in areas of spatial overlap; and (3) Investigate the relationships between SAV species and density, invertebrate biomass, and juvenile LMB growth to assess the possibility that *Egeria* provides a food-rich LMB nursery habitat. This report is the final report to the USBR and summarizes major findings for each task. Other major deliverables are supplied with this report as separate documents.

Task 1. Influence of abiotic and biotic factors on largemouth bass abundance, distribution and diet, and the entire nearshore fish assemblage. Bimonthly field surveys were conducted from October 2008 through October 2010 at 33 locations throughout the Delta. Fish were sampled via electroshocking, and SAV was sampled and water quality measured at the same locations. SAV sampling revealed that *Egeria* was the dominant macrophyte species throughout the year, composing approximately 79-96% of the sampled biomass over the course of the sampling effort. Bayesian models were used to assess the importance of SAV density, water temperature, Secchi depth, electrical conductivity, and season as predictors of both juvenile (young-of-the-year) and older (Age 1+) LMB abundance. SAV density was the strongest predictor of juvenile abundance, with the highest numbers found at intermediate SAV densities. Maximum juvenile abundance at intermediate SAV densities is consistent with previous research within the native range of LMB, and with laboratory studies suggesting that intermediate SAV densities provide protection from predators without

excessive foraging inhibition. In contrast, SAV density was not a reliable predictor of abundance for age 1+ LMB, indicating that these fish are not reliant on SAV for structure. While nearly all sites had SAV at least seasonally, age 1+ LMB were still sampled where SAV was not present or at very low densities.

Notably, there was substantial variation in modeled abundance estimates across the range of SAV density sampled for both juveniles and age 1+ LMB. This variability indicates that while model estimates present a general relationship, other parameters not measured in this study, may also have important influences on distribution. For example, the location of LMB breeding areas may create localized areas of juvenile abundance, regardless of SAV density, and age 1+ fish may be able to use a many types of submerged structures as habitat (e.g., tule reeds, artificial structures created by humans). Indeed, a major result from these surveys is that age 1+ LMB were largely ubiquitous, with presence found at 92% of sampling events. Juvenile LMB were slightly less common, with presence found at 67% of sampling events.

Over 3,300 diet samples were collected during the two-year survey, with fish sizes ranging from 25 – 763mm fork length. Stomach content analyses revealed a preponderance of SAV-associated prey, suggesting that foraging far from the shoreline or in deeper, open waters was uncommon. Overall, juvenile LMB diets were composed of small crustaceans (e.g., amphipods) and aquatic insects. Across all seasons and SAV densities, the most important contributor to the age 1+ LMB diet was the red swamp crayfish, *Procambrus clarkii.* Among the fish consumed, other centrarchids and demersal fishes (e.g. introduced gobies) were most common. Native fishes in the piscivorous LMB diet included prickly sculpin *Cottus asper,* tule perch *Hysterocarpus traski*, Pacific lamprey *Entosphenus tridentatus* (ammocoetes), threespine stickleback *Gasterosteus aculeatus,* Sacramento blackfish *Orthodon microlepidotus*, and hitch *Lavinia exilicauda*. However, native fishes were less common in the diet than crayfish and introduced fishes. Despite limited to common overlap with juvenile striped bass *Morone saxatilis* and threadfin shad *Dorosoma petenense*, these POD fishes were rare in the LMB diet.

Growth rate of juveniles, condition of age 1+ LMB, quantity of food consumed, and average energy density of consumed prey were compared between sites with low, medium, and high SAV. Among the juveniles, apparent growth rate was highest in low density SAV areas, despite the fact that YOY at low density SAV sites were not consuming prey of a higher energy density. YOY at low density SAV sites also consumed a greater quantity of food, possibly due to reduced competition in these areas and/or relatively straightforward foraging conditions compared to areas with higher SAV densities. In contrast, condition factor ($K=10^{5*}$(body mass/fork length^3)) for age 1+ LMB was highest at medium and high SAV densities. Average prey energy density did not differ between SAV density categories, but LMB at medium and high density SAV sites consumed more fish and crayfish compared to low density SAV sites. Thus, while abundance of age 1+ LMB was not significantly related to SAV density, prey densities may be higher where SAV is denser, resulting in improved LMB condition.

To understand how SAV density, prey composition, and turbidity interact to influence LMB prey choice, a series of mesocosm studies were conducted using adult LMB and live *Egeria* collected from the Delta. When only vegetated habitat was available, increases in vegetation density resulted in decreased predation success. However, when placed in an environment with both open water and vegetated areas, and given a choice to forage on prey associated with either of these habitats, LMB preyed mainly on open water species as opposed to vegetation-associated species. When turbidity was also varied, the predation rate on open water species was significantly lower. Thus, recent analyses demonstrating an increase in water clarity in the Delta may leave open water species more vulnerable to predation. However, results from the field suggest that LMB rarely need to leave nearshore areas to locate prey, and SAV densities are variable enough to allow successful foraging.

Task 2. Abundance and diet composition of LMB and other predators co-occuring with delta smelt. Additional surveys for LMB and other potential predators of adult and larval delta smelt were conducted March-June of 2011 in areas where delta smelt presence has been consistently documented by IEP surveys (Cache Slough complex and Suisun Marsh). Due to the difficulty of detecting delta smelt in predator stomach contents, a genetic assay was used to assess the presence of delta smelt DNA in predator stomach contents. Twenty species and 813 individual potential predators were subjected to genetic analysis of stomach contents, of which 559 were inland silversides. Thirty LMB were sampled, only 2 of which (~7%) were positive for delta smelt DNA. In contrast, 69 silverside samples (12%) were found to have predated delta smelt larvae, with the highest percentages of positive samples in the Deepwater Ship Channel and Sacramento River. The incidence of silverside predation was negatively associated with turbidity. However, further studies will be necessary to determine turbidity levels at which silverside predation on delta smelt is reduced or limited, and to assess the bioenergetic demand of silversides on larval delta smelt and specifically relate predation to delta smelt abundance.

Task 3. Influence of the SAV species and biomass on invertebrate community composition and biomass. To understand the relationship between juvenile LMB, SAV, and the macroinvertebrate community at a finer scale, 9 of the 33 sites used for Task 1 were selected for sampling of invertebrates dwelling on SAV in August of 2010. At each site, small samples of SAV were collected and all invertebrates on the sampled SAV were identified. In addition, diet and daily growth rate were analyzed using juvenile LMB captured at the same sites. We found that SAV communities differed greatly across our sites, but shifts in dominant species did not impact invertebrate community composition or overall abundance of invertebrates. Abundance of SAV was the primary factor associated with increases in the abundance of invertebrates commonly consumed by largemouth bass. Thus, there is no evidence to suggest that monospecific stands of *Egeria* support less diverse invertebrate communities in the Sacramento-San Joaquin Delta, but they likely do support higher abundances of invertebrates, as *Egeria* comprises a significant fraction of SAV Delta-wide. Notably, predominately invasive communities of SAV in the Delta support predominately native communities of invertebrates.

Growth rates of juvenile largemouth bass differed significantly across sites, but was not associated with whether or not sites were dominated by *Egeria*. . This study combined with data from Task 1 suggest that both the actual communities of SAV and invertebrates are less important to juvenile largemouth bass in the Delta than the overall landscape of the SAV patch. The presence of SAV provides large quantities of possible prey items, but if the SAV is too dense then foraging efficiency is highly impacted.

<u>Task 1:</u> Influence of abiotic and biotic factors on largemouth bass abundance, distribution and diet, and the entire nearshore fish assemblage

1.1 Nearshore fish assemblage by season and Delta region

To examine the distribution of LMB and other nearshore fishes with respect to SAV and water quality parameters, 33 locations were sampled on a bimonthly basis from October 2008 – October 2010 (Figure 1). Determination of sampling location and all sampling methods are described in detail in a supplementary metatdata report, which is enclosed in a supplementary file: "2008-2010 Nearshore Survey Database Metadata Report for Sacramento-San Joaquin Electrofishing and Submerged Aquatic Vegetation Surveys."

Specific analyses and findings regarding the abundance of LMB and LMB diet composition with respect to environmental conditions in the Delta are described in detail in two other enclosed deliverables, both article manuscripts drafted for publication in peer-reviewed journals: (1) "Invasion of Brazilian waterweed *Egeria densa* facilitates expansion of an estuarine population of largemouth bass *Micropterus salmoides;* (2) Brazilian waterweed *Egeria densa* influences condition and diet of largemouth bass *Micropterus salmoides* in the Sacramento-San Joaquin Delta. A third, published manuscript, entitled "Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass," is also included. This article describes mesocosm experiments in which the effects of SAV density and turbidity on LMB foraging success and prey choice were investigated.

In addition to specific analyses on LMB (detailed in enclosed deliverables), we have also summarized the fish assemblage of the nearshore community by season and Delta geographic region (Figures 2a – e). Species abundance was calculated by dividing the number of individuals of each species sampled by the number of meters electrofished. As 41 different species were sampled, species were placed in logical groups, to create pie charts illustrating assemblage. Species groups were as follows:

- **Bass & sunfish**: bluegill sunfish, green sunfish, largemouth bass, miscellaneous sunfish (hybrids or too small to identify to species), redear sunfish, smallmouth bass, spotted bass, white crappie, warmouth sunfish.
- **Natives**: hitch, Pacific lamprey, prickly sculpin, Sacramento blackfish, Sacramento sucker, Sacramento pikeminnow, Sacramento splittail, steelhead/rainbow trout, tule perch, white sturgeon, chinook salmon, delta smelt.
- **Nonnative minnows**: common goldfish, golden shiner, common carp, red shiner, fathead minnow.
- **Catfish**: black bullhead, brown bullhead, white catfish, channel catfish.
- **Others**: shimofuri goby, yellowfin goby, bigscale logperch, western mosquitofish, rainwater killifish.
- **STB & TFS**: striped bass, threadfin shad.
- **Silversides**: inland silverside.

Across seasons and geographic regions, bass and sunfish made up over half of the nearshore community. This pattern was particularly evident in Central and Eastern Delta regions, where bass and sunfish were the vast majority of fishes (Figure 2a and 2c). Native fishes were a significant portion of the community only in the North Delta (Figure 2b). However, this relatively large average catch per meter of native fishes arose mainly from a single location, an oxbow area off the main channel of Miner Slough. This site, characterized by dense SAV in 2009, with significantly reduced SAV density in 2010, was apparently a population center for Sacramento blackfish, as multiple size classes of this species were captured there every single sampling event. The western Delta (Figure 2e) also had relatively high catches of native fish, composed mainly of tule perch captured in Sherman Lake. The southern Delta had lower proportions of centrarchids compared to central and eastern regions, with the remaining portion made up most of silversides, and the POD species, juvenile striped bass and threadfin shad. Interestingly, juvenile striped bass and threadfin shad made up a significant portion of the community in 2009, but dropped off significantly in 2010. Overall, these regional comparisons are similar to previous analyses conducted by Brown and Michniuk (2007), in which they compared nearshore fish communities between the early 1980s and the early 2000s using randomly selected sites surveyed by the California Department of Fish and Wildlife Resident Fish Survey. They reported substantial increases in centrarchid abundance in central, eastern, and southern regions, with an overall decline of native fishes and the highest proportions of native fishes remaining in northern and western regions (Brown and Michniuk, 2007). Our summary of the nearshore fish community suggests that these general trends have continued through the remainder of the decade.

Figure 1. Map of 33 electrofishing, water quality, and SAV sampling locations. Letters next to each location indicate the site type (TS = terminal slough, C = channel, R = river, FI = flooded island.) Regions used for comparison of fish assemblages are indicated with ovals.

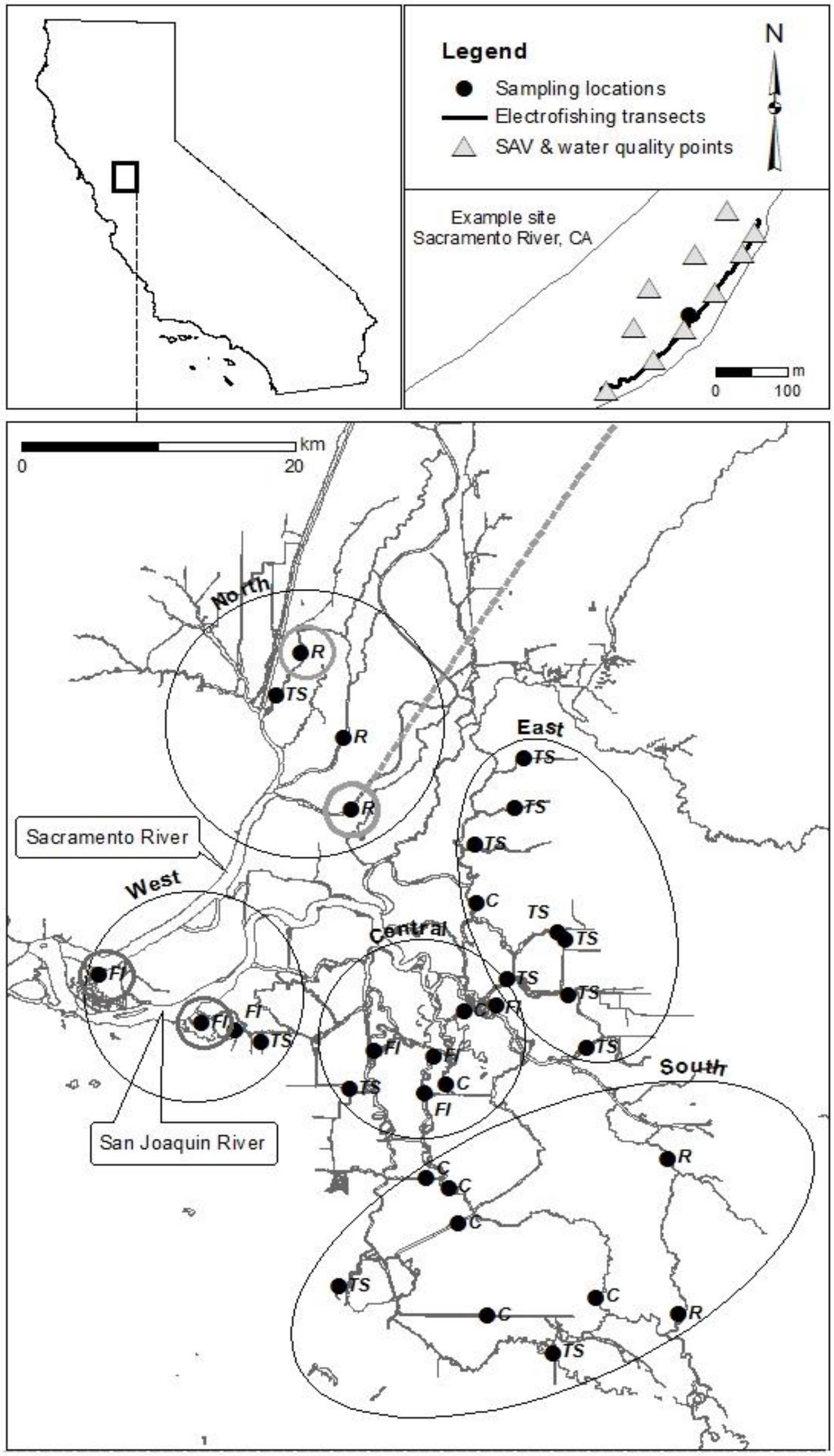


Figure 2a. Seasonal fish assemblages for the Central Delta, based on average catch per meter for each species group (winter-spring = December, February, April; summer – fall = June, August, October sampling months). Species groups are detailed in the above summary.

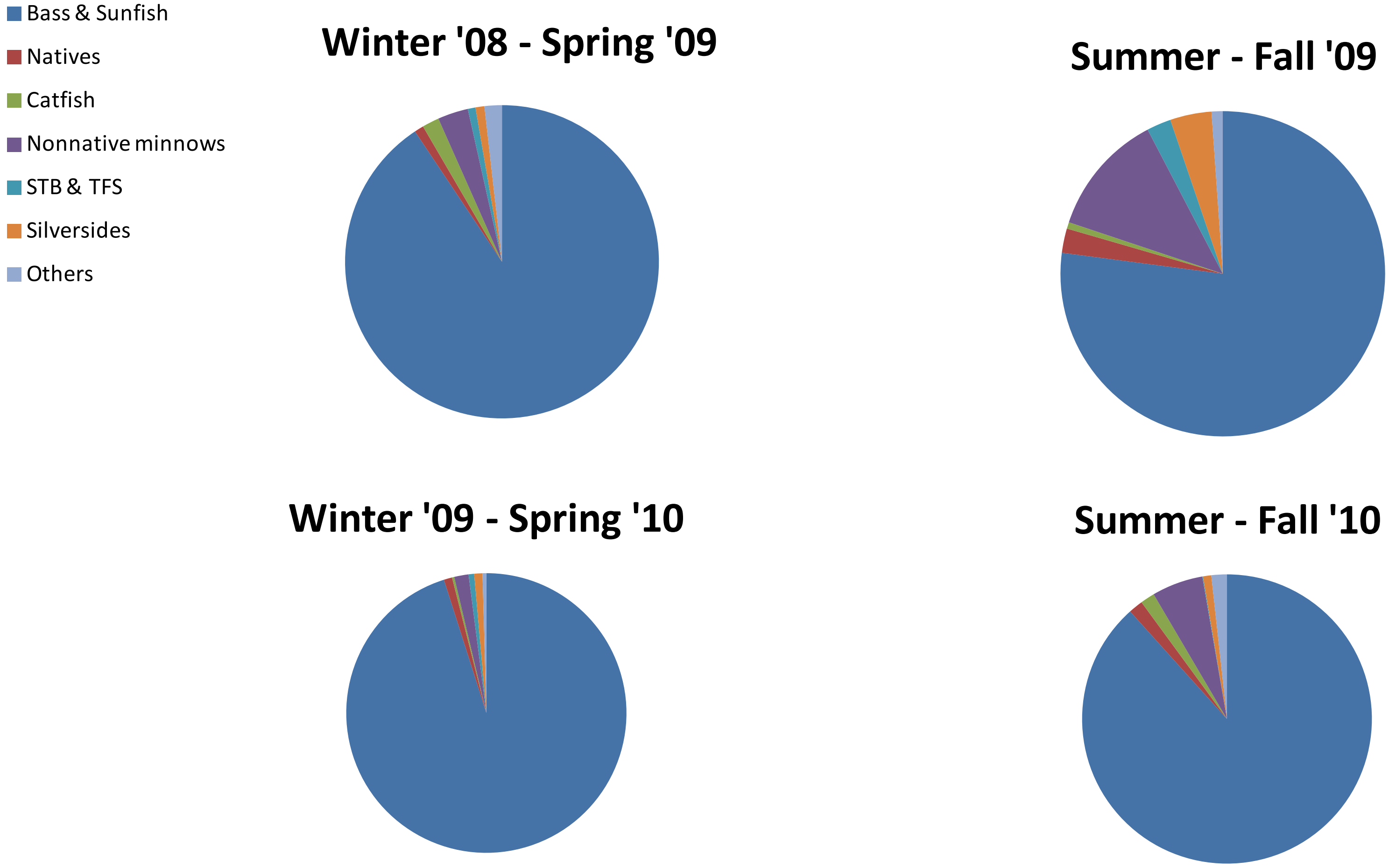


Figure 2b. Seasonal fish assemblages for the North Delta.

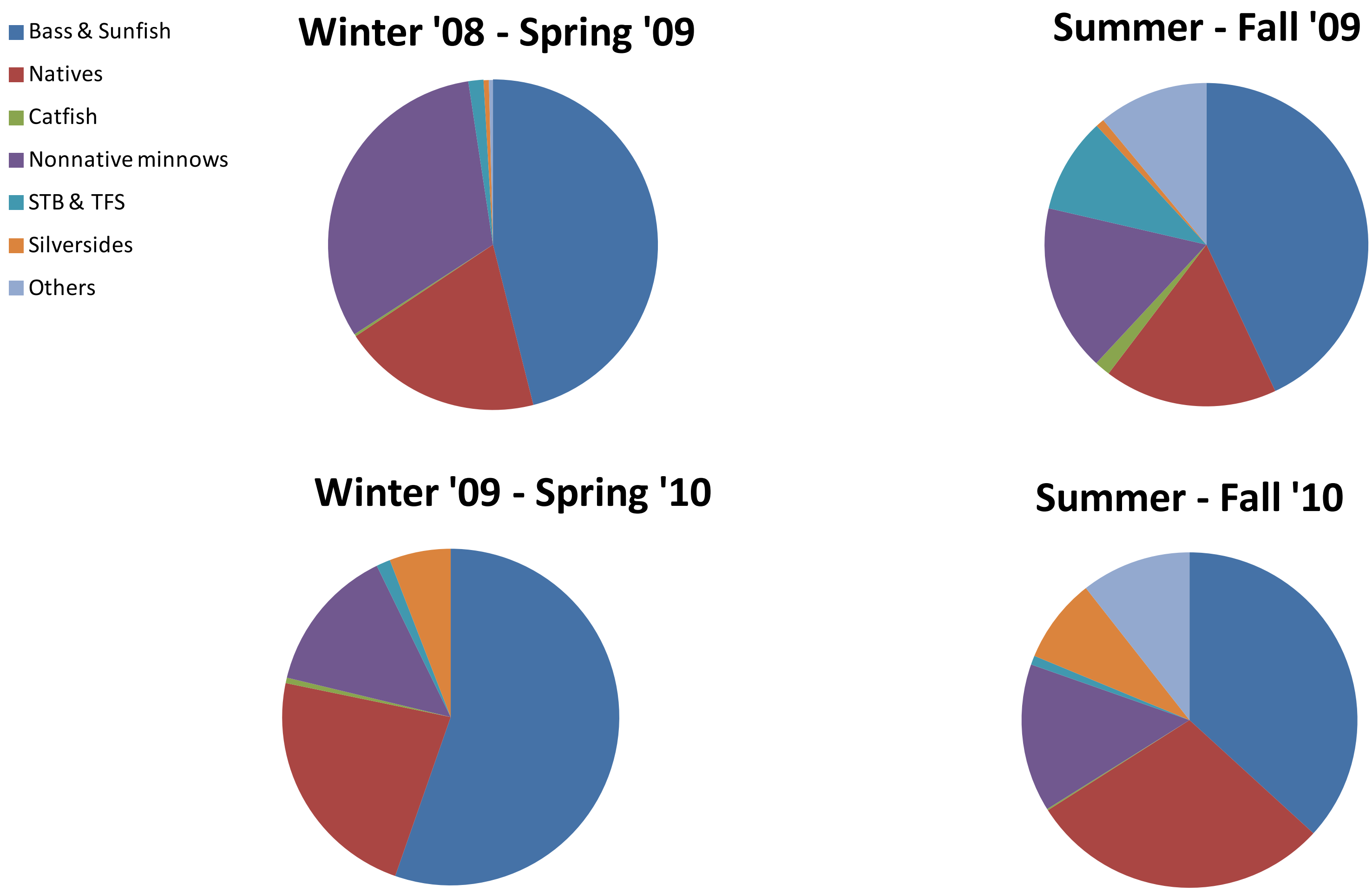


Figure 2c. Seasonal fish assemblages for the East Delta.

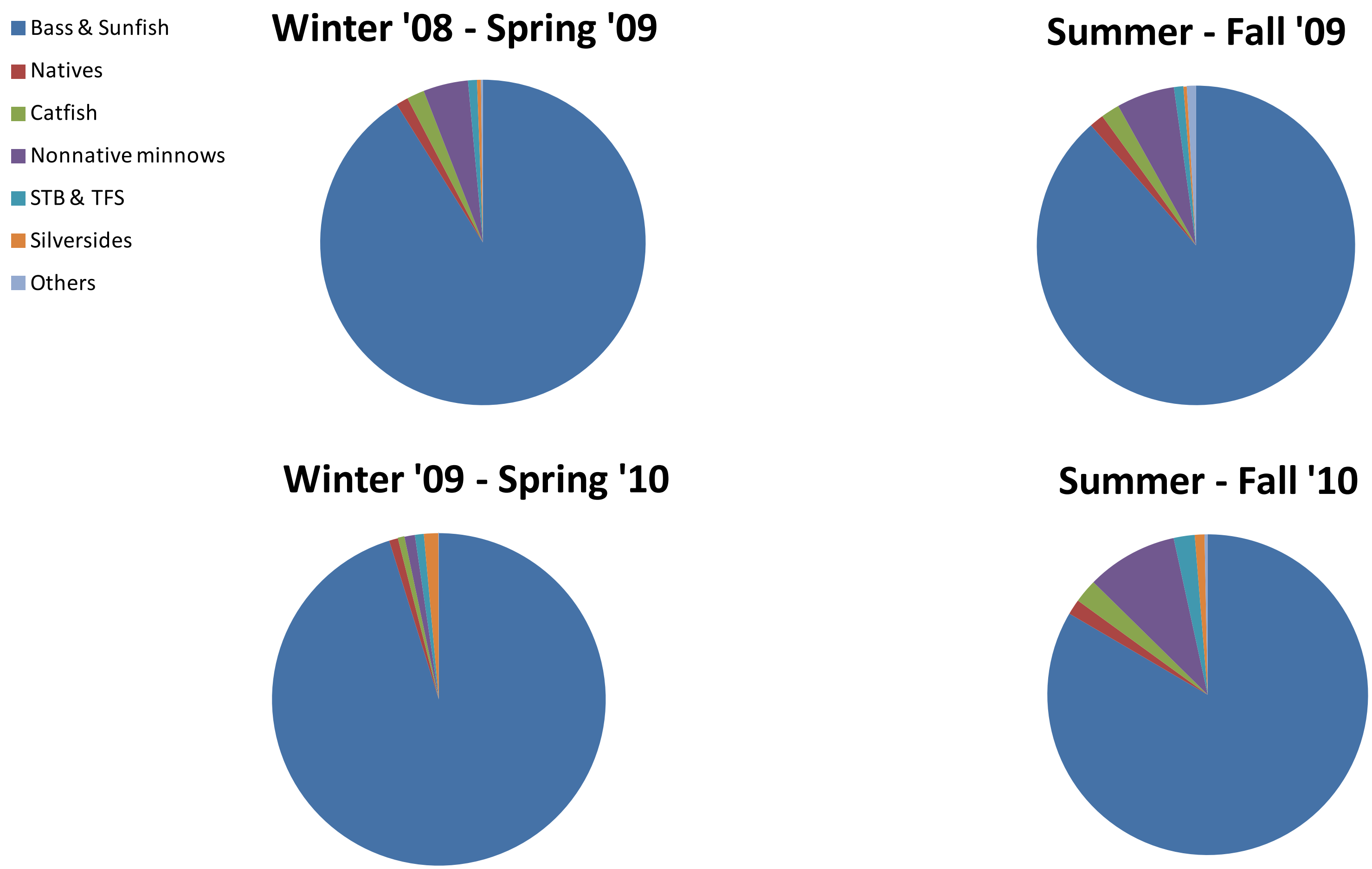


Figure 2d. Seasonal fish assemblages for the South Delta.

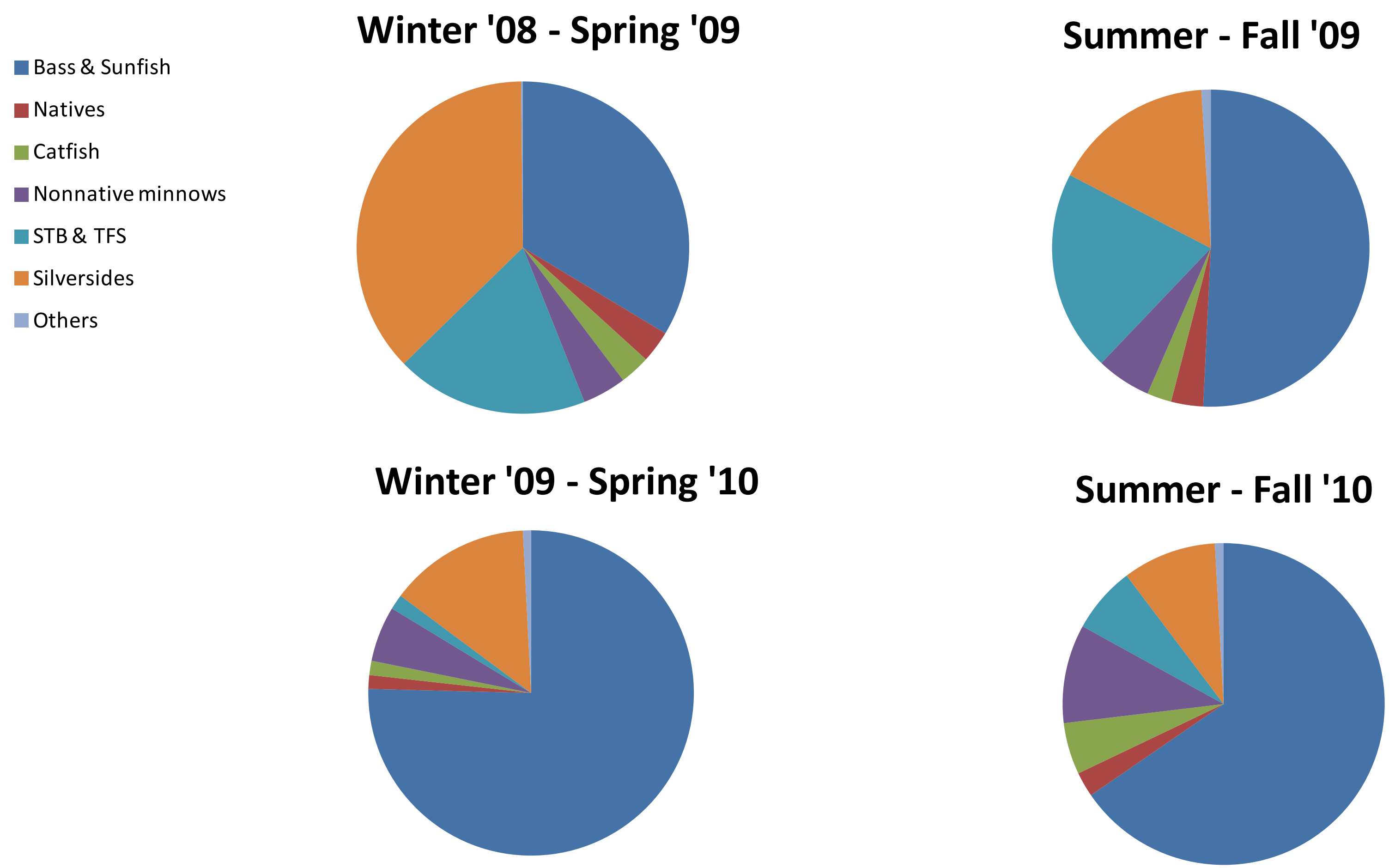
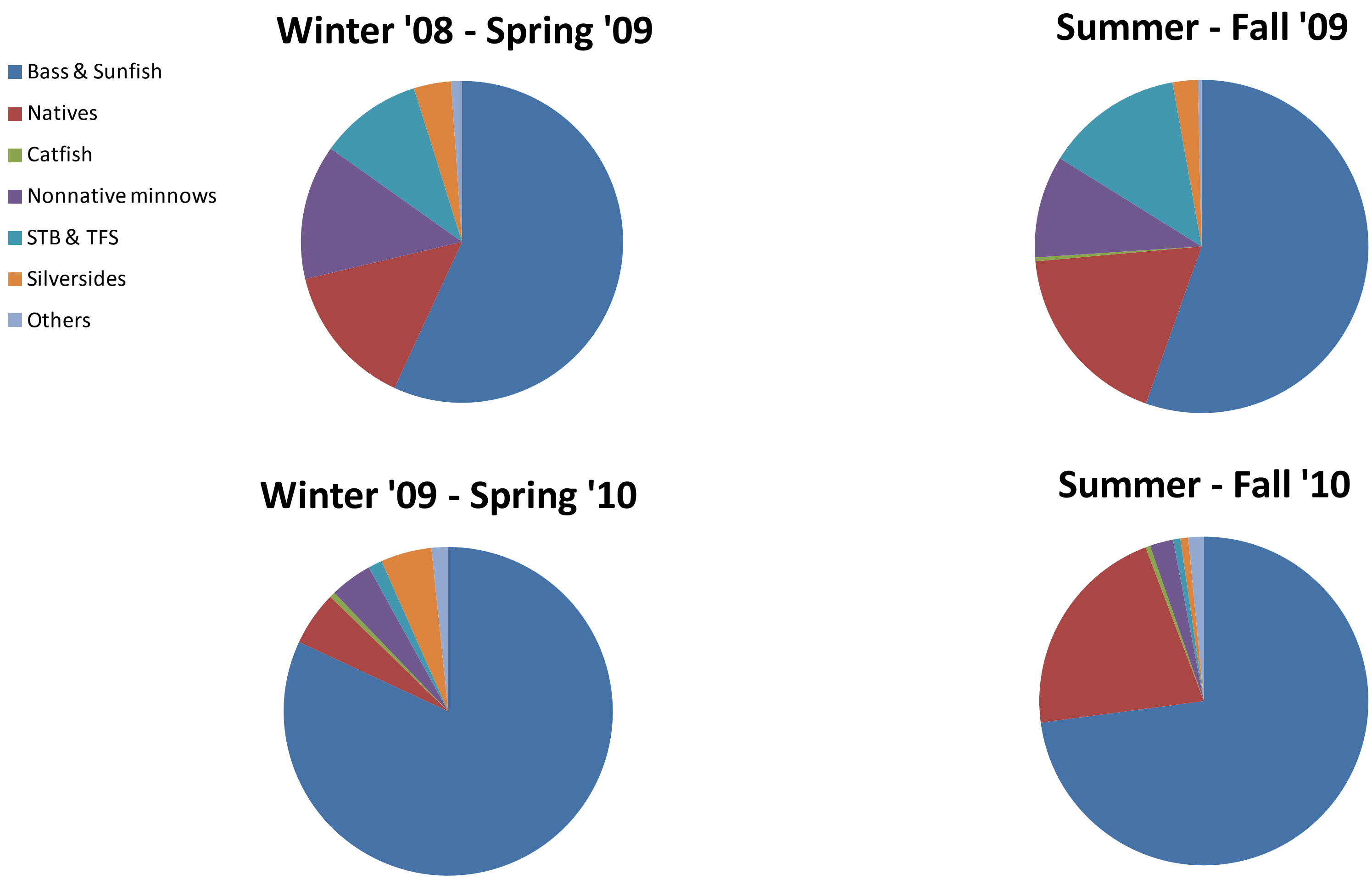


Figure 2e. Seasonal fish assemblages for the West Delta.



1.2 Seasonal diet composition for juvenile largemouth bass and age 1+ largemouth bass

Analysis:

For information on largemouth bass diet sample collection and analysis methods, see Weinersmith et al. *in prep* (Task 1 deliverable). The relative importance of the various prey items in the diet of age 1+ and YOY largemouth bass was examined using the prey-specific index of relative importance, %PSIRI, a metric that accounts for: 1) the proportion of fish that have that food type in their stomach; 2) the relative abundance of that food type in their diet; and 3) the relative biomass of that food type in their diet (Brown et al. 2012). Percent prey specific frequency of occurrence ($\%FO_i$), percent prey specific abundance ($\%PA_i$), percent prey specific weight ($\%PW_i$), and %PSIRI were calculated as:

$$\%PA_i = \frac{\sum_{j=1}^{n} \%A_{ij}}{n_i}, \%PW_i = \frac{\sum_{j=1}^{n} \%W_{ij}}{n_i}, \%FO_i = \frac{n_i}{n} * 100,$$

$$\%PSIRI_i = \frac{\%FO_i \times (\%PN_i + \%PW_i)}{2},$$

where $\%A_{ij}$ is the percent of the prey counts in stomach *j* that are prey type *i*, $\%W_{ij}$ is the percent of all food in stomach *j* that is of prey type *i*, n_i is the number of stomachs containing prey type *i*, and *n* is the number of stomachs containing at least some contents (i.e., empty stomachs are excluded from this analysis). We choose %PSIRI over percent index of relative importance (%IRI) as %IRI weights frequency of occurrence more heavily than weight or count data, and is not additive across prey categories or taxonomic levels (e.g., %IRI value calculated at the genus level will not necessarily equal the sum of %IRI values for species in the genus that were calculated individually) whereas %PSIRI is additive (Brown et al. 2012). Prey were categorized to facilitate interpretation of the data (Table 1), and %PSIRI was calculated for YOY in summer (Table 2) and winter (Table 3), as well as for age 1+ largemouth bass in summer (Table 4) and winter (Table 5). As in Weinersmith et al. *in prep,* data were grouped by SAV density (low, medium, high) in order to assess whether SAV density influenced diet composition.

Juvenile largemouth bass fed primarily on aquatic insects, zooplankton (copepods and cladocerans), and amphipods. Age 1+ largemouth bass fed on decapods (mainly red swamp crayfish, *Procambrus clarkii),* amphipods, aquatic insects, and a suite of fish species (listed in Table 1), mainly other centrarchids and demersal fishes. Values of PSIRI were substantially lower for native fishes and POD species (juvenile striped bass and threadfin shad), across all SAV densities and seasons. Notably, the PSIRI values for decapods were higher than for any fish species of group of fishes. Red swamp crayfish were frequently observed in SAV beds during sampling.

Table 1. Prey categories for %PSIRI analysis.

Prey type
Largemouth bass
Largemouth bass and unidentified *Micropterus*
Other centrarchids
Bluegill sunfish, redear sunfish, warmouth, black crappie, and unidentified centrarchids or *Lepomis*
Other introduced fishes
Golden shiner, mosquitofish, rainwater killifish, carp, inland silverside, and unidentified cyprinids
Demersal fishes
Yellowfin goby, shimofuri goby, bigscale logperch, catfish, and unidentified gobies or sculpins
Striped bass
Threadfin shad
Native fish species
Sacramento blackfish, hitch, tule perch, threespine stickleback, pacific lamprey, and prickly sculpin
Decapods
Crayfish and shrimp

Table 1 (cont'd).

Prey Type
Amphipods
Hyallidae, Gammaridae, and *Corophiidae*
Copepods & cladocerans
Other crustaceans
Isopods and mysids
Aquatic insects
Diptera, Ephemeroptera, Odonata, Hemiptera, Trichoptera, Hymenoptera, Coleoptera, Lepidoptera, and Megaloptera
Other invertebrates
Arachnida, Nemertea, Oligochaeta, Euhirudinea, Acarina, Flatworm, and *Corbicula*

Table 2. YOY largemouth bass %PSIRI and empty stomachs during summer months (June, August, and October). Summer 2008 includes only October 2008.

	Summer 2008			Summer 2009			Summer 2010		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Largemouth bass	0.0	1.1	0.0	0.0	0.4	0.0	1.5	0.8	0.5
Other centrarchids	10.0	1.5	1.4	0.0	0.2	1.0	0.0	1.7	1.5
Native fish	0.0	0.0	0.0	5.1	0.0	0.0	0.0	0.0	0.0
Striped bass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Threadfin shad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Demersal fish	0.0	0.0	3.5	0.0	0.0	0.6	0.2	0.0	0.0
Other fish	0.0	1.5	0.0	0.0	1.6	1.6	0.0	1.8	0.4
UnID fish	0.0	0.5	2.0	2.0	0.3	2.8	3.3	1.6	0.1
Other Vertebrates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Decapods	3.7	6.1	0.0	3.1	1.5	1.1	1.0	2.7	0.0
Amphipods	54.7	42.1	43.2	25.5	52.4	47.8	37.4	39.0	48.6
Copepods & cladocerans	0.2	17.1	17.6	10.9	11.2	13.6	11.6	13.1	18.4
Other Crustaceans	2.1	1.1	0.0	0.0	1.5	0.6	0.1	0.0	0.0
Insects	29.3	29.0	31.7	53.2	30.8	30.9	44.8	39.0	30.6
Other Invertebrates	0.0	0.0	0.5	0.1	0.1	0.0	0.0	0.4	0.0
Stomachs sampled	16	78	81	86	138	186	65	239	134
% empty stomach	37.5	15.4	9.9	9.3	14.5	10.2	10.8	12.6	10.4

Table 3. YOY largemouth bass %PSIRI and empty stomachs during winter months (December, February, April).

	Winter 2009			Winter 2010		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
Largemouth bass	0.0	0.0	0.0	0.0	0.0	0.0
Other centrarchids	0.0	0.0	0.0	0.0	0.0	0.9
Native fish	6.1	1.9	1.8	0.0	1.0	0.0
Striped bass	0.0	0.0	0.0	0.0	0.0	0.0
Threadfin shad	0.0	0.0	0.0	0.0	0.0	0.0
Demersal fish	4.9	0.9	1.8	0.0	0.4	0.0
Other fish	0.0	0.0	0.0	0.0	0.0	0.0
UnID fish	11.8	1.1	0.7	0.0	3.4	0.2
Other Vertebrates	0.0	0.0	0.0	0.0	0.0	0.0
Decapods	6.9	4.0	2.1	4.8	2.4	2.5
Amphipods	13.4	52.3	30.6	25.5	27.6	38.1
Copepods & cladocerans	1.4	9.9	16.7	30.4	20.0	10.0
Other Crustaceans	2.0	3.3	3.3	0.0	2.2	0.3
Insects	53.5	26.5	43.0	39.3	43.0	47.1
Other Invertebrates	0.0	0.0	0.1	0.0	0.0	0.9
Stomachs sampled	16	80	216	33	140	134
% empty stomach	25.0	28.8	23.6	36.4	26.4	37.3

Table 4. Age 1+ largemouth bass %PSIRI and empty stomachs during summer months (June, August, and October). Summer 2008 includes only October 2008.

	Summer 2008			Summer 2009			Summer 2010		
%PSIRI	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Largemouth bass	0.0	0.0	0.0	2.8	3.8	12.4	0.0	6.0	8.9
Other centrarchids	9.6	17.0	27.3	7.9	16.3	15.4	3.1	11.3	12.1
Native fish	0.0	3.3	2.6	5.7	3.3	6.9	3.2	5.3	6.6
Striped bass	0.0	0.0	0.0	1.4	0.0	0.2	1.6	0.0	0.0
Threadfin shad	0.0	4.0	2.6	0.0	0.4	0.0	0.0	0.0	0.7
Demersal fish	9.1	15.6	28.0	6.1	6.5	0.8	13.4	2.6	1.5
Other fish	3.7	3.3	0.0	4.7	2.1	1.3	0.0	3.3	0.6
UnID fish	21.1	17.4	12.9	14.4	9.3	14.4	8.3	9.8	7.2
Other Vertebrates	0.0	0.0	0.0	1.4	0.3	0.0	0.0	0.6	0.0
Decapods	41.3	31.9	19.9	17.0	28.5	25.8	21.0	27.5	25.5
Amphipods	9.6	3.3	1.3	18.0	19.3	6.1	26.3	13.7	10.4
Copepods & cladocerans	0.0	0.0	0.0	0.2	0.1	0.5	0.3	0.7	1.3
Other Crustaceans	0.0	0.6	0.0	0.0	1.8	1.6	0.4	1.7	0.4
Insects	5.6	3.0	5.3	17.6	8.1	13.1	22.4	17.1	23.9
Other Invertebrates	0.0	0.6	0.0	2.4	0.5	1.5	0.1	0.3	0.7
Stomachs sampled	34	32	45	113	228	244	71	181	161
% empty stomach	20.6	6.3	15.6	38.9	24.6	18.0	11.3	14.4	16.8

Table 5. Age 1+ largemouth bass %PSIRI and empty stomachs during winter months (December, February, April).

	Winter 2009			Winter 2010		
%PSIRI	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Largemouth bass	1.4	1.1	2.5	9.2	1.2	1.8
Other centrarchids	3.5	7.6	18.4	2.8	7.9	15.1
Native fish	2.5	2.5	4.0	5.0	7.9	2.8
Striped bass	0.0	0.0	0.0	0.0	0.0	0.0
Threadfin shad	0.7	0.8	1.4	0.0	0.0	0.0
Demersal fish	16.9	6.2	6.0	9.7	10.1	4.9
Other fish	0.2	1.1	1.4	2.6	2.1	0.0
UnID fish	9.1	9.3	16.0	13.0	9.0	6.5
Other Vertebrates	0.0	0.0	0.0	0.0	2.6	1.8
Decapods	26.2	40.8	31.1	25.5	33.9	41.7
Amphipods	21.5	18.6	9.1	11.2	12.4	13.7
Copepods & cladocerans	0.4	0.9	0.1	1.2	0.0	3.0
Other Crustaceans	0.0	2.5	1.3	1.9	4.8	0.2
Insects	10.3	7.5	7.7	17.3	6.7	8.4
Other Invertebrates	7.3	1.2	1.1	0.5	1.5	0.1
Stomachs sampled	78	103	157	42	146	98
% empty stomach	9.0	9.7	10.2	9.5	20.5	26.5

1.3 Observed rate of largemouth bass predation on Pelagic Organism Decline fishes

One of the major study objectives was to determine the frequency of co-occurrence between LMB and POD fishes (specifically, threadfin shad, juvenile striped bass, delta smelt, and longfin smelt), and the frequency of direct predation on POD fishes by LMB.

Overall, the frequency of occurrence of POD fishes in the LMB diet was extremely low, with only juvenile striped bass and threadfin shad found in low numbers among the LMB sampled (total frequencies of occurrence of 0.2% and 0.6%, respectively). For longfin and delta smelt, their lack of appearance in LMB diets can be explained by the fact that we never (longfin smelt) or very rarely (delta smelt) found these prey species in the same sites as LMB. In contrast, juvenile striped bass were seen in the same sites with LMB moderately often, and threadfin shad often co-occurred with LMB, and yet we still rarely saw those fish in LMB diets.

Longfin smelt were never sampled during the study. Delta smelt were sampled only on a few occasions in April 2010 at north Delta locations in Steamboat Slough, Sacramento River (above Vieira's Boat Launch), and the upper reaches of Miner Slough. A single LMB was also sampled at both Steamboat and Miner Slough locations, and only one of these fish had stomach contents. This single diet sample contained 2 unidentifiable fish, a crayfish, as well as numerous mysids and hemipteran insects.

Tables 6 and 7 provide data on the number of piscivorous-sized LMB, the number of threadfin shad or juvenile striped bass, with the corresponding number of POD fishes found in LMB diet samples. Co-occurrence of LMB and threadfin shad occurred at 24 of the 33 sites, with the majority of instances in the South Delta. There was, however, no strong seasonal trend in co-occurrence. Diet samples were taken from 257 LMB (>175 mm FL) where they co-occurred with threadfin shad. Only 3 of these samples contained threadfin shad, suggesting a very low predation rate. Threadfin shad were also observed in six LMB stomachs sampled from sites where TFS were not also sampled (no evidence of co-occurrence at the time of sampling). Overall, of 1,183 diet samples from piscivorous-sized LMB (>175mm), only nine samples contained threadfin shad.

Relative to threadfin shad, co-occurrence with juvenile striped bass (<125mm) was limited. LMB and juvenile striped bass were sampled together at only 9 of the 33 sampling locations, again primarily in the south Delta (Table 7). Sixty-nine LMB (>175mm) were sampled for diet from these cases of co-occurrence, and only one of these contained a juvenile striped bass. Over all sampling sites, juvenile striped bass were observed in 3 LMB diet samples.

Table 6. Number of LMB and threadfin shad (TFS) sampled at all instances of their co-occurrence, with the number of TFS found in diet samples.

Body of Water	Date	LMB (>175mm)	TFS	TFS in Diet Sample
Northern Delta				
Miner Slough	10/22/2009	3	79	0
	2/19/2010	11	4	0
	4/16/2010	9	2	0
	8/17/2010	1	1	0
Steamboat Slough	8/21/2009	3	1	0
Central Delta				
Latham Slough	10/13/2008	1	1	0
	8/11/2009	8	10	0
Mildred Island (south)	10/13/2008	1	127	0
Mildred Island (north)	6/10/2009	2	1	0
Western Delta				
Big Break	10/21/2008	5	1	0
	12/23/2009	5	1	0
Dutch Slough	6/22/2009	9	26	0
Sherman Lake	4/20/2009	6	1	0
	4/14/2010	2	2	0
Eastern Delta				
Beaver Slough	6/11/2009	9	8	0
	8/4/2010	1	3	0
	10/8/2010	2	28	0
Bishop Cut	10/7/2008	2	7	0
	6/8/2009	2	1	0
Disappointment Slough (east)	10/7/2008	1	15	0
	12/1/2008	8	1	0
	8/16/2010	5	2	0
Disappointment Slough (west)	12/1/2008	1	12	0
Fourteen Mile Slough	10/15/2008	5	4	0
	8/16/2010	9	1	0
Hog Slough	10/20/2008	2	1	0
Little Potato Slough	10/20/2008	2	5	0
Sycamore Slough	6/15/2010	3	1	0
Whites Slough	8/3/2010	2	2	0

Table X. (cont'd)

Body of Water	**Date**	**LMB (>175mm)**	**TFS**	**TFS in Diet Sample**
Southern Delta				
Grant Line Canal	10/28/2008	**4**	**65**	**3 (*2 samples w/ TFS)**
	12/12/2008	1	1	0
	6/16/2009	21	1	0
	8/20/2009	1	4	0
	8/6/2010	5	1	0
	10/12/2010	3	32	0
Italian Slough	10/24/2008	2	142	0
	10/24/2008	**1**	**142**	**1**
	12/9/2008	1	6	0
	8/18/2009	4	1	0
Middle River (south)	10/28/2008	1	29	0
	4/21/2009	1	11	0
	6/16/2009	1	12	0
	8/19/2009	6	2	0
Middle River (north)	4/21/2010	1	3	0
	8/19/2010	3	1	0
San Joaquin River (south)	10/27/2008	1	15	0
	12/11/2008	7	112	0
	12/11/2008	**1**	**112**	**1**
	6/17/2009	2	20	0
	8/19/2009	3	3	0
	4/15/2010	3	1	0
	6/23/2010	1	4	0
	8/18/2010	1	14	0
San Joaquin River (north)	10/27/2008	1	28	0
	2/13/2009	1	4	0
	4/22/2009	16	2	0
	6/17/2009	9	8	0
	8/14/2009	2	7	0
	10/21/2009	2	97	0
	2/18/2010	3	1	0
	4/15/2010	5	2	0
	6/23/2010	2	2	0
	8/16/2010	2	3	0
Sugar Slough	10/28/2008	2	26	0
	4/21/2009	3	13	0
	6/16/2009	5	7	0
	8/19/2009	1	1	0
	12/18/2009	1	1	0
	4/21/2010	1	8	0
	6/17/2010	3	2	0
	8/18/2010	1	6	0
	10/12/2010	2	45	0

Table 7. Number of LMB and juvenile striped bass (STB) sampled at all instances of their co-occurrence, with the number of juvenile striped bass found in LMB diet samples.

Body of Water	Date	LMB (>175mm)	STB (<125mm)	STB in Diet Sample
Northern Delta				
Miner Slough	4/21/2010	1	1	0
Central Delta				
Mildred Island (south)	10/13/2008	1	1	0
Southern Delta				
Grant Line Canal	10/28/2008	5	1	0
	12/12/2008	1	9	0
	8/20/2009	1	1	0
Italian Slough	10/24/2008	3	2	0
Middle River (south)	10/28/2008	1	6	0
	4/21/2009	1	11	0
	8/19/2009	6	2	0
San Joaquin River (south)	10/27/2008	1	22	0
	4/21/2009	3	3	0
	8/19/2009	3	2	0
San Joaquin River (north)	10/27/2008	1	1	0
	4/22/2009	16	1	0
	10/21/2009	2	3	0
Sugar Slough	10/28/2008	2	19	0
	4/21/2009	3	5	0
	10/12/2010	1	12	0
	10/12/2010	**1**	**12**	**1**
Victoria Canal	10/24/2008	16	18	0

<u>Task 2:</u> Abundance and diet composition of largemouth bass and other predators co-occurring with delta smelt

A significant drawback to visual analysis of stomach contents is that after substantial decomposition occurs, consumed prey items become unidentifiable. In the analysis of the largemouth bass diet samples (Task 1), efforts were made to identify ingested fish by examining samples for the cleithrum bone, which takes longer to digest and whose morphology is unique for some families or genera (Hansel et al., 1988; and supplementary deliverable, "Largemouth bass diet analysis: identification of ingested fishes in the Sacramento and San-Joaquin Delta using cleithra"). However, even with these measures taken to identify ingested fish, a significant portion of fish prey could not be identified (Task 1 Tables 2-5). Furthermore, many of the sites sampled in the nearshore fishes survey carried out from 2008 – 2010 were locations not typically inhabited by delta smelt, an ESA-listed fish of interest given its recent decline as part of the POD. Given limited overlap between largemouth bass and delta smelt, and an extremely low likelihood of detecting delta smelt via visual analysis of stomach contents, we made a special effort to sample largemouth bass and other potential delta smelt predators in locations delta smelt were the most likely to inhabit for spawning and larval/juvenile rearing purposes. In addition, *in lieu* of visual diet analyses, stomach samples of putative predators were subjected to genetic assays designed specifically for detection of delta smelt DNA.

Genetic techniques for identification of ingested prey are increasingly common in efforts to understand predation and trophic dynamics because they can accurately identify prey species only present in very small amounts (Symondson, 2002). A TaqMan assay for delta smelt was recently developed, and found to accurately detect delta smelt DNA up to 36-hours post-ingestion (Baerwald et al., 2012). This assay was used in limited sampling of inland silversides in 2010 to demonstrate predation of delta smelt larvae. This assay was used for all diet samples collected for Task 2, including largemouth bass. The approach involved extensive collaboration with scientists from the Genomic Variation Laboratory at University of California, Davis (Drs. Melinda Baerwald and Bernie May), Cramer Fish Sciences (Dr. Gregg Schumer), and California Department of Water Resources (Brian Schreier). To fund the genetic testing component, collaborators received funding from the Interagency Ecological Program (IEP) and the State Water Contractors Association.

Sampling was completed in June of 2011, and genetic analyses were completed in January of 2012. Delta smelt presence in the IEP surveys of the spring Kodiak trawl (adults) 20-mm (larvae and small juveniles) was reviewed from the last five years to determine areas to sample predator such that the likelihood of sampled putative predators overlapping with delta smelt was maximized. During the spring months, delta smelt presence is concentrated in the North Delta Cache Slough complex and the Suisun Marsh. Boat electroshocking was conducted in randomly selected locations in Lindsey and Cache Sloughs, Liberty Island, and the Deepwater Ship Channel. Putative predators were also collected from existing IEP surveys in both the

Cache Slough Complex and Suisun Marsh (CDFW Spring Kodiak Trawl, US Fish & Wildlife Service Beach Seine, and the UCD Suisun Marsh trawling and beach seining program).

Overall, 20 species and 813 individual diet samples were subjected to genetic analysis of stomach contents (Table 8). The most abundant putative predator was the inland silverside, with 559 samples. Thirty LMB were sampled, only 2 of which (~7%) were positive for delta smelt DNA. In contrast, 69 silverside samples (12%) were found to have predated delta smelt larvae, with the highest percentages of positive samples in the Deepwater Ship Channel and Sacramento River. Of all the geographic regions sampled, the highest percentage of samples that were positive for delta smelt DNA was the Sacramento River (at Spring Kodiak trawl sampling stations 704 and 706, near Rio Vista, and station 724, above the confluence with Cache Slough; map of sampling sites available at http://www.dfg.ca.gov/delta/projects.asp?ProjectID=SKT); however, only 6 samples were collected from the Sacramento River, all inland silversides (Table 8). Within the Cache Slough Comples, while a comparable number of samples were collected from Cache Slough, Deepwater Ship Channel, Liberty Island, and Lindsey Slough. Among these areas, the proportion of samples that were positive for delta smelt DNA was highest in the Deepwater Ship Channel. However, with low sampling resolution and no population estimates for predators or prey, data are not currently available for modeling the proportion of the delta smelt population impacted by predation.

To determine whether incidences of predation were correlated with specific environmental conditions (regardless of geographic area), generalized linear models were conducted to assess the likelihood of predation with respect to water temperature, turbidity, conductivity, dissolved oxygen, and pH. Only turbidity emerged as having a significant relationship with the likelihood of predation, with a slightly lower probability of predation in higher turbidity conditions. Further funding has already been provided from IEP to conduct laboratory trials on the effect of turbidity on larval smelt predation by silversides.

However, a higher density of sampling for both larval delta smelt (USFWS beach seine) and putative predators (2011 electroschocking and USFWS beach seine) in Liberty island allows an assessment of the distribution of predators testing positive for delta smelt DNA with delta smelt distributions. Results reveal that predators consume larval delta smelt before they are sampled in the larval fish survey (highest number of silversides testing positive for delta smelt in March and April, while larval smelt were not detected until May and June). In addition, larval smelt were distributed more in the open water, while inland silversides had a more shoreline distribution. All figures depicting these results can be found in the supplementary file for this Task, "Genetic Detection of Predation on Larval Delta Smelt", Spring 2012 IEP Workshop presentation, given by Brian Schreier, California Department of Water Resources).

As the nearshore area of the Cache Slough Complex is thought to be a haven for native fishes but is infrequently sampled, spatial analyses were also used to identify fine-scale patterns of distribution and abundance of fish species. Native fish species composed approximately 41%

of the community assemblage. Tule perch and Sacramento sucker, the most abundant native species, occurred along shallow, vegetated banks. Juvenile chinook salmon frequented nearshore habitats along channel corridors and backwater sloughs. Delta smelt occupied shallow open water habitat near exposed beaches and riprap banks, and along a submerged road in Liberty Island. These community assemblage analyses were presented at the October 2012 Delta Science Council conference. The presentation, entitled “Fish communities of the North Delta,” was given by Denise De Carion of UC Davis and is enclosed as a deliverable for this Task.

Table 8. Number of putative predator samples taken from each geographic region with each sampling method. All samples are categorized by the result of the Taqman assay for delta smelt DNA, negative (no delta smelt DNA detected) or positive (evidence of predation).

	Cache Slough		**Deepwater Ship Channel**		**Liberty Island**		**Lindsey Slough**		**Sacramento River**	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
Beach Seine										
Exopaleamon shrimp					3					
Largemouth Bass					1					
Inland silverside			1	1	112	11				
Sacramento pikeminnow			2		11	1				
Shimofuri goby					18	1				
Striped bass					4	1				
Threadfin shad					1					
Yellowfin goby			1		2					
Boat electroschocking										
American Shad					1		1			
Bluegill sunfish	2		1				6	1		
Black crappie	6		1				7			
Chinook salmon			13	1			2			
Exopaleamon shrimp				1						
Green Sunfish	3	1					6			
Largemouth Bass	12				2		13	2		
Inland silverside	110	7	51	2	21	4	106	13		
Prickly sculpin	2									
Redear sunfish	2						12			
Sacramento pikeminnow	8		6		6		8	1		
Sacramento sucker	1									
Shimofuri goby			1							
Spotted bass							1			
Striped bass			23		8		6			
Threadfin shad	1		10		2	1	5			
Tule perch	1	1	1				3			
Three-spined stickleback								1		
Yellowfin goby	1						1			

	Cache Slough		Deepwater Ship Channel		Liberty Island		Lindsey Slough		Sacramento River	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
Kodiak Trawl										
Inland silverside	2		1	17					3	3
Striped bass										
Threadfin shad			1							
Otter Trawl										
Inland silverside										
Sacramento pikeminnow										
Striped bass										
Grand Total	**151**	**9**	**113**	**22**	**192**	**19**	**177**	**18**	**3**	**3**

Table 8 (cont'd). Predator samples for Suisun Marsh, categorized by positive or negative results for predation on delta smelt.

	Suisun Marsh						
	Lower Denverton	**Middle Nurse**	**Upper Nurse**	**Montezuma**		**Suisun Marsh (proper)**	
	Negative	Negative	Negative	Negative	Positive	Negative	Positive
Beach Seine							
Inland silverside						60	3
Striped bass						3	
Kodiak Trawl							
Inland silverside				5	5		
Striped bass						1	
Otter Trawl							
Inland silverside				1			
Sacramento pikeminnow				1			
Striped bass	3	2	3	11		8	
Grand Total	**3**	**2**	**3**	**18**	**5**	**72**	**3**

<u>Task 3:</u> Influence of the SAV species and biomass on invertebrate community composition and biomass

One hypothesis for the increased population size of LMB in the Delta is that juvenile recruitment has increased as a result of the expansion of *Egeria.* A link between SAV and juvenile survival is plausible, given the results from Task 1 demonstrating increased abundance of juvenile LMB at intermediate SAV densities. However, the mechanism by which SAV benefits juvenile LMB has not been identified. The objective of this task was to determine whether SAV may provide increased prey densities for juvenile LMB, which may in turn result in increased growth rate and survival. Another (not mutually exclusive) hypothesis for how SAV may benefit LMB is that it provides refuge from predators. Only the increased prey density hypothesis was investigated here, not predator refuge.

Previous studies have also shown that the species of macrophyte may influence the community composition of macroinvertebrates (Toft et al., 2003). However, the relationship between invertebrate community and submerged vegetation has not previously been investigated. Thus, the goal of this study was to sample SAV on a finer scale than the approach used in Task 1 (described in the enclosed deliverable, "2008-2010 Nearshore Survey Database Metadata Report for Sacramento-San Joaquin Electrofishing and Submerged Aquatic Vegetation Surveys"), and characterize the macroinvertebrate abundance and composition with respect to the species and density of SAV. A second goal was to relate juvenile LMB growth and diet to the SAV density, and community and of macroinvertebrates. A subset of 9 of the 33 sites sampled for Task 1 were used for this effort.

Results show that total SAV biomass density, rather than SAV species, influence macroinvertebrate abundance (positive relationship). Similarly, SAV species did not directly affect fish diet or fish growth. Fish consumed larger prey items at sites where vegetation was distributed more patchily than at other sites, and fish growth was highest at those sites. This supports the idea that the general SAV landscape (patchy vs. consistent density) may be more important to juvenile fishes than the SAV species or absolute density.

Sampling methods, results and relevant figures, and major findings are all described in the enclosed deliverable, "The effect of submerged aquatic vegetation on invertebrate communities and juvenile largemouth bass (*Micropterus salmoides*) growth and diet," a draft manuscript prepared for submission to a peer-reviewed journal (to be determined).

A brief summary of summary of the macroinvertebrate community in SAV beds in the Delta is also included in a second enclosed deliverable for this task, a poster presentation given at the October 2012 Delta Science Council conference, "Vegetation-associated macroinvertebrates communities in the Sacramento-San Joaquin Delta."

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