RMP Food Web Analysis; Data Report on Gut Contents of Four Fish Species

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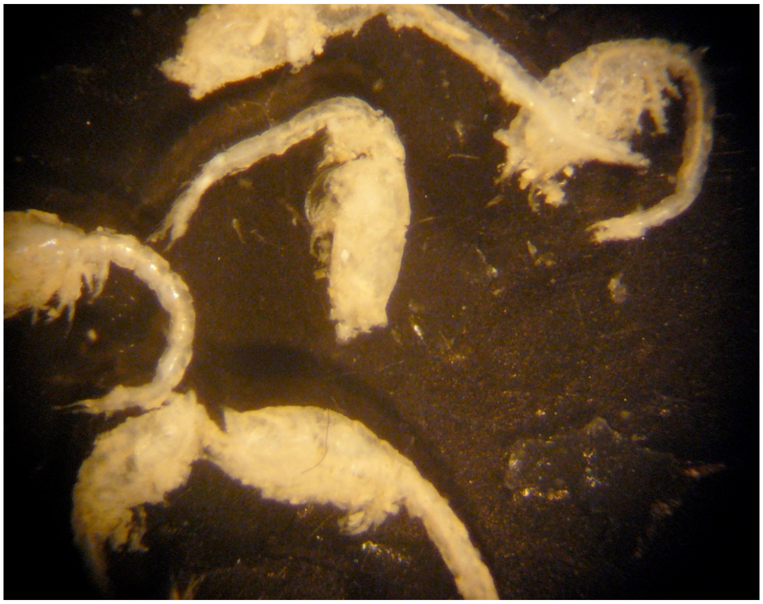

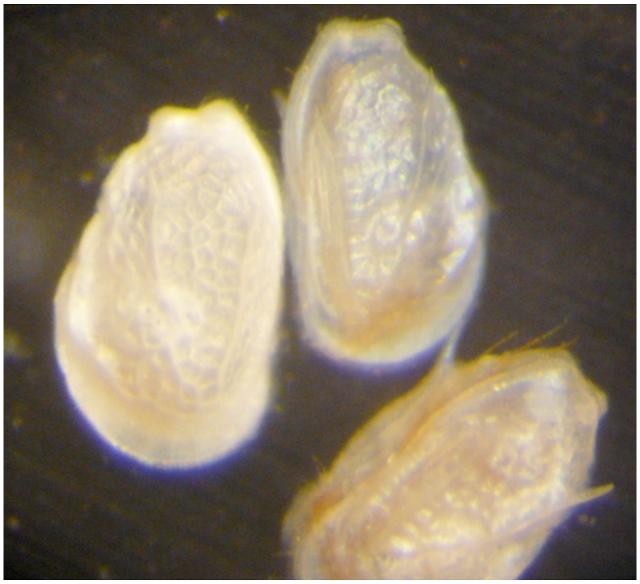

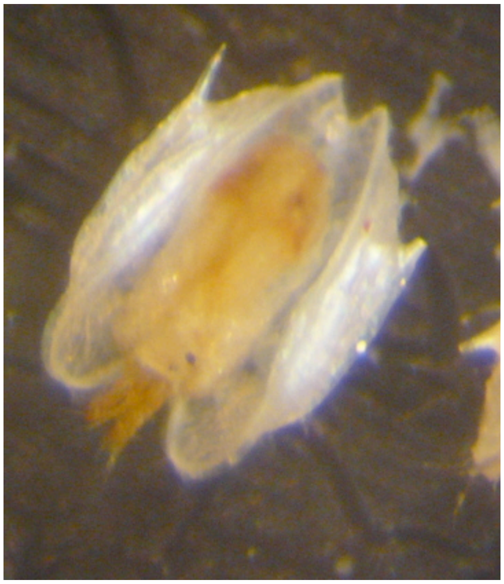

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Cover images photographed by the author from gut content samples. Top left: *Nippoleucon hinumensis* (Asian cumacean). Top right: *Synidotea sp.* (Crustacea: Isopoda). Bottom left and right: *Spinileberis sp.* (Crustacea: Ostracoda).

EXECUTIVE SUMMARY

Diet data (as average percentage by volume of contents) from moderate-sized samples (30 – 45) of four fish species (shiner perch, white croaker, topsmelt, and Mississippi silverside) were obtained from RMP and other available fish samples. In this study as well as in other information available for San Francisco Bay, all four species fed mainly on benthic crustaceans, with minor reliance on water-column prey. White croaker fed on larger organisms than the other three species, in apparent agreement with its usual placement at a higher trophic level in bioaccumulation models. Topsmelt and Mississippi silverside were most similar, such that the available diet information on these two species does not offer a ready explanation for their marked difference in tissue mercury content. Apparent spatial variation in the diet of all four species is confounded with differences in time of sampling and/or size of fish. Continued work on fish diets, along with direct measurement of contaminant levels in key prey and associated sediment, are promising approaches to understanding the linkage between sediment contamination and human and wildlife receptors.

INTRODUCTION

This data report is a contribution to the SFEI special study entitled "Development of a refined conceptual model for aquatic food webs in San Francisco Bay." The study proposed to address the following fundamental questions:

1. How is the SF Bay food web organized?
2. What is the relative role of sediments vs. the water column as transport pathways of contaminants to biota?
3. Is there food-web driven spatial variation in contaminant uptake?

The interest in food web structure comes from the long-standing appreciation of biomagnification of certain contaminants through cumulative food-chain transfers (beginning with the work of Hunt and Bischoff 1960). Food-chain models are commonly used by regulators to link pollution sources with human health (e.g., SFRWQCB 2006, 2008). Present models of the food chain (or, in recognition of its complexity, "food web") in San Francisco Bay (e.g., Gobas and Wilcockson 2003) are simple models embedded in the larger context of modeling contaminant fate. Implicit in RMP funding of this study, as well as related studies (Roberts et al. 2000, Greenfield 2002), is the hope that refinements in food-web models can help lead to better understanding of contaminant transfer, especially as it applies to fish consumption by humans and wildlife.

This laboratory portion of the study was to use existing fish samples of four species to obtain sufficient information to determine the proportion of benthic vs. pelagic prey, as well as to refine knowledge of the trophic position of the prey spectrum used by each fish. A secondary question, to be addressed if data permit, was to examine any spatial patterns (i.e., station –to-station differences) in prey usage.

In his presentation to the RMP Technical Review Committee, Ben Greenfield presented the following hypothetical framework for the broader program:

Species	Prey types	Contaminant pathways	Spatial variation in diet
Shiner surfperch	Epibenthic invertebrates	Sediment and boundary layer	No
White croaker	Benthic and epibenthic invertebrates and small fish	Sediment and boundary layer	No
Topsmelt	Algae and zooplankton	Water column	No
Silverside	Epibenthic, terrestrial invertebrates, and zooplankton	Sediment and water column	No

The focus of this report is dietary evaluation of the species listed in the chart (shiner perch *Cymatogaster aggregata*, white croaker *Genyonemus lineatus*, topsmelt *Atherinops affinis*, and Mississippi silverside *Menidia audens)*. I will present gut contents data for moderate-sized samples (30-45 fish) of each species and address whether the information confirms or modifies the table entries for prey type, contaminant pathway, and spatial variation. These samples, based on preexisting collections, generally for other purposes, are not definitive, and so where appropriate, I will also consider these questions in light of other unpublished shiner perch and white croaker data from San Francisco Bay: my own work based on Oakland Middle Harbor samples in April and June 1999, and also a previous RMP study (Roberts et al. 2000). In addition, I reference published findings for topsmelt and silverside from China Camp marsh (Visintainer et al. 2006).

METHODS

List of Abbreviations

avg. %.	Average percent volume
BL.	Body length exclusive of antennae and setae
cm.	Centimeter
g.	Gram
mg.	Milligram
mm.	Millimeter
PL.	Prosome length, a measure of the "fat part" of a copepod
PSI.	Percentage similarity index
RMP.	Regional Monitoring Program
SL.	Standard length, the distance from snout to base of tail fin (end of hypural plate)

SFRWQCB San Francisco Regional Water Quality Control Board

TL. Total length

unid. Unidentified

USEPA United states Environmental Protection Agency

Vol. Volume

wtd. avg. %. Weighted average percent, as defined in previous subsection

µg. Microgram

Materials

Fish sources included the following:

- RMP Fish 2006 - Shiner perch and croaker
- EEPS small fish Hg 2006 and 2007 – topsmelt and silverside
- EEPS endocrine effects to small fish 2007 (Kevin Kelley) – shiner perch

A complete list of specimens is given in Appendix A, along with summarized gut contents data.

The croaker and perch samples all consisted of gut tracts removed from frozen trawl-caught specimens, fixed in formalin, then transferred to alcohol after a freshwater leaching. As described in the results, this method of obtaining gut samples worked well for croaker but not for shiner perch. Topsmelt and silverside samples were whole fish fixed in the field and then transferred to alcohol after a 24-hr leaching. These were fish of opportunity, retained after sufficient samples were obtained for the primary goal of mercury analysis. The Kelley fish were measured to the nearest mm standard length (SL), whereas the RMP fish lengths were recorded to the nearest cm TL. I adjusted the Kelley lengths to TL by multiplying by 1.255 (based on a single specimen 90 mm SL. 113 mm TL) and then rounding to the nearest cm to match the RMP data. I applied the same procedure to the standard lengths from my 1999 study, using the ratio 1.255 for shiner perch and 1.167 (again based on a single specimen) for white croaker.

Gut Analysis

When possible (i.e., with topsmelt and silverside), I measured fish to the nearest mm and weighed to the nearest mg on an electronic balance. In the best cases, I removed the gut from the bottle or fish, stripped off liver, fat deposits, etc., rinsed in tap water, then blotted on a paper towel and weighed to the nearest mg. Perch and croaker guts were perforated with a fine scalpel point before blotting to help remove excess fluid from the gut cavity. I then opened the entire digestive tract and removed the contents into a dish under low (120 or 240 x) magnification. The gut was then blotted again and re-weighed, and the mass of the contents determined by subtraction. Some guts were poorly preserved or otherwise not intact, or for other reasons a major part of the contents had spilled into the bottle, precluding this double weighing procedure for determining mass of contents. In other cases, contents weighed less than 1 mg, the limit of precision of my balance. In such cases, I estimated contents mass based on counts and measurements of prey items. In rare cases, large prey items were weighed directly. Counts of very numerous items were made on subsamples.

I examined prey items at higher magnifications (240-500 x) as necessary under a stereoscopic dissecting scope (Wild M5 with aftermarket 20 x eyepieces and a reticle). I identified invertebrate prey with the aid of the revised Light and Smith Manual (Carlton 2007), which also served as the authority for the names of taxa. Both by visual estimation and through counts and volume estimates based on simple geometric models (generally, spheres for eggs, cylinders or series of cylinders for other shapes), I estimated the percentage of the volume of the contents attributable to each identified taxon. Items judged to represent <1% of the contents were recorded as present in trace amounts but not used further in the analysis. Cumulative tallies of identified prey for each fish species are given in Appendix B, which also lists the food categories into which I grouped items for analysis.

Most often, crustacean prey were present as empty exoskeletons or skeletal fragments having very little mass. In making percent volume determinations, I assumed unidentified granular, waxy, or other matrix material was derived from the identified contents in proportion to the volume represented by the identified exoskeletal remains. Because the interest here is in food-chain transfer of organically incorporated contaminants, I ignored sand grains and, in the rare occasions when they appeared to represent more than 5% of the gut contents mass, I estimated their mass and subtracted it from the contents mass.

Data Reduction

Assembling a useful data set from raw gut contents data requires some reduction in complexity. This is true for several reasons. First, it is not always possible to identify partially digested items to the same taxonomic level, and so lumping to higher taxa is necessary for reasonable comparisons. A special case of this first reason in the present study is that identification of many of the crustacean taxa simply requires higher magnification of tiny parts than I could achieve. Second, our knowledge of the trophic positions, contaminant levels, etc., of most species in the Bay is very general and imprecise, and therefore some lumping on ecological criteria (e.g., all medium-sized benthic crustaceans) is appropriate, at least until such time as more detailed trophic and contaminants information is obtained. Related to the first two reasons for lumping is the reasonable guess that slightly different taxa will turn out to be the same or very similar as regards their contaminant concentrations, and that taking the analysis to very fine taxonomic detail, even if magnification and specimen condition allowed for it, might be a waste of effort. Moreover, some observations suggest that size can be of equal importance to taxonomy in placing an organism in a particular trophic level (Wyatt 1976).

As a result of such considerations, I lumped, e.g., all copepods with a prosome length <0.5 mm into a group I called "small copepods etc." I added the ostracods into this group because they were all small (≤0.7 mm), and are presumably suprabenthic, like the small harpacticoids that make up the overwhelming majority of this group. Another *ad-hoc* assignment was to divide the small benthic and epibenthic crustaceans into two size categories, "crustacean 1" and "crustacean 2." This was done to accommodate the finding that most such crustaceans in these samples were either small cumaceans or considerably larger corophiid amphipods [a 2.5 mm *Nipoleucon hinumensis* (cumacean, "crustacean 1") was estimated to have a mass of 0.17 µg, whereas a 9 mm *Corophium heteroceratum* (amphipod, "crustacean 2") was estimated to weigh 7 µg, a 40-fold difference expected to be ecologically significant]. Exact assignments of all taxa to food categories are given in Appendix B. The full matrix of food category percentages for each fish is given in Appendix A.

I summarize the percentage data in two ways. The first is simply the average percentage made up by a food category for a given group of fish. I call this "average percent," a measure that weights the percentage volume equally, regardless of the mass of contents in individual fish. Alternatively, I estimate the percentage of the total mass consumed by the group that is attributable to each category, which I obtain by multiplying each percentage volume by the mass of contents for that fish, summing the products for each food category, and dividing by the total mass consumed by that species. I call this "weighted average percent," a measure that gives more weight to categories that are eaten in larger absolute amounts. When the two measures differ substantially, it normally indicates that large and small fish diets differ in the proportion of the item in question; in the present study, the difference was also a good check for bias resulting from the sampling procedures for shiner perch and white croaker. For modeling purposes (in the absence of bias), if the species is treated as a single size group, then weighted average percent will give the truer measure of diet composition.

I did not calculate the popular "Index of Relative Importance" (IRI) because I think frequency of occurrence and (especially) numbers of individual items consumed are irrelevant in the present biomagnification context, and their confounding with mass in IRI would be unhelpful in any future modeling exercise. I did compute the percentage similarity index (PSI), based on weighted average % data, which is simply the sum of the minimum percentages over all food categories in any two-fish species comparison (see Roberts et al. 2000), to facilitate a comparison among species for general information.

Roberts et al. (2000) examined shiner perch and white croaker from Redwood Creek, San Leandro Bay, Oakland Inner Harbor, and San Pablo Bay. Their report tabulates average percent by weight of food items identified to the lowest possible taxonomic rank. I summarized these data, equivalent to average % volume as used elsewhere in the present report, by combining the Roberts et al. data into categories as close as possible to those defined here in Appendix B, with two exceptions: because they reported fewer small harpacticoids and more frequent mysids, I lumped all copepods and ostracods together into "O-C pods", and I put mysids into "other animals."

In the 1999 Middle Harbor study, contents of the entire gut were examined but only ranked in order of their apparent relative volumes. These ordinal data are given here for shiner perch and white croaker in Appendix C.

RESULTS

Species Comparisons

Of the four species investigated, white croaker was easily the most different, with more than half its diet composed of shrimp and fish, as opposed to the smaller crustacean diet of the other three species (Figure 1). White croaker resembled the other three species most closely in its occasionally substantial utilization of the ubiquitous cumacean *Nippoleucon hinumensis* (food category "crustacean 1"). As expected based on size and taxonomic relatedness, topsmelt and silverside diets were most similar to each other, and, perhaps surprisingly, shiner perch was more similar to these little fishes than to white croaker. These relationships are summarized in Table 1.

Table 1. Percentage similarity of the diets of four fish species.

PSI BY WTD. AVG. % VOL. OF FOOD CATEGORIES			
	PERCH	TOPSMELT	SILVERSIDE
CROAKER	27	18	12
PERCH		56	46
TOPSMELT			81

With the possible exception of the fish portion of the white croaker diet (discussed below), all the major contributors to the diets of all four species were creatures that dwell mainly on or near the bottom. The reader is once again cautioned that these findings may not be representative of long-term, baywide averages. General characteristics of the four collections, and more specific results from the four species are given in the following subsections.

Shiner perch

Preserved guts from 44 RMP and Kelley specimens, fish that ranged in length from 9 to 14 cm TL, were examined. In addition, a single 11-cm (TL) specimen collected in Oakland Harbor in 1999 (all I had left) was included for reference. The gut contents of the 1999 specimen weighed 423 mg, whereas the average contents mass of the 44 preserved guts was 80 mg. This result, along with the following observations, suggests that > 80% loss of contents occurred during the combined processes of freezing, thawing, dissection, fixation, rinsing, and preservation in alcohol. Discouraged by the results of randomly selected specimens from Oakland Harbor and San Leandro Bay, I examined bottles and hand-picked 11 specimens that appeared to be intact and to contain substantial contents. These eleven, which are included in the average of the 44 specimens cited above, averaged 183 mg contents apiece.

Like topsmelt and Mississippi silverside, shiner perch has a simple gut morphology with two major bends and no easily identified demarcation between stomach and intestine. The two bends can be considered to define three sections of approximately equal length, though the first (closest to the pharynx) has a greater diameter than the second and third. In the preserved guts, the first section tended to have very little in it, and in fact, eight of the 44 RMP-Kelley specimens were entirely empty (Appendices A & B). Without an esophageal constriction, excision of these non-fixed guts appears to have allowed a major release of contents at one or more steps in the process. Use of the data requires the assumption that this loss has not created a bias in the observed volume percentages. I saw few reasons to question this assumption, and none regarding the major contributing food categories, as detailed below.

Table 2 gives the unweighted and weighted average volume percentages of the 14 food categories, showing that four of the categories (macroalgae, shrimp, insect, and *Philine*) were not found in this fish. By both measures of average volume contribution, "crustacean 2" and polychaetes together composed about half of the shiner perch diet. This agreement between the two measures indicates these categories were represented about equally in nearly empty stomachs as well as those with substantial mass of contents. By contrast, the large relative discrepancy in the two measures for the food category "fish" (3.4% avg. % vs. 0.1% wtd. avg. %) was due to two anchovy eggs, which were the only contents found in one shiner perch gut, thereby contributing 100% of the contents of this individual, but contributing only an estimated 1 mg to the total consumption by shiner perch in the study.

White croaker

Preserved guts of 45 white croaker specimens, 15 each from South Bay, Oakland Harbor, and San Pablo Bay, were examined, only three of which were empty. These fish ranged in length from 21 to 34 cm TL, with fish from San Pablo Bay significantly larger (p=.038, Fisher-Freeman-Hamilton test; see Table 3). White croaker has a muscular, blind-sac stomach from which contents are extruded past a ring of pyloric caeca into a convoluted intestine. There appeared to be little loss of contents except in the few specimens where some part of the gut had been severed during removal from the fish. The average contents mass was 1.4 g. The diet was varied, with 11 of the 14 food categories represented (all except diatoms, small copepods, and insects; Table 4) but with substantial spatial variation (Figure 2).

San Pablo fish contained mainly the shrimp *Crangon franciscorum*, with minor contributions of fish and amphipods, and little else. In contrast, South Bay and Oakland croaker ate more fish, along with substantial numbers of the predatory slug-like gastropod *Philine* sp. The croakers in the Oakland sample also contained substantial masses of clams and mussels; some of the latter appeared to have been torn from pilings, as indicated by the presence of wood fragments, hydroids, macroalgae, and, in one case, a chipped white croaker tooth.

Of the fish prey that could be identified (based on some combination of head anatomy, vertebral counts, otolith shape, shape of gill arch and number of rakers), all appeared to be northern anchovy. In several cases, the anchovy stomach in turn contained only amphipods (*Ampelisca* sp.?), in approximately gram quantities. So even though northern anchovy is typically a midwater planktivore (Kimmerer 2006), its identification in this sample does not represent an exception to the primarily benthic focus of white croaker foraging.

Topsmelt and Silverside

The interest in topsmelt and Mississippi silverside, both members of the New World silverside family Atherinopsidae, stems from preliminary findings of the RMP Small Fish mercury project. Consistently, paired samples have shown marked differences, with the introduced silverside having significantly higher Hg concentrations than topsmelt from the same sites (Greenfield et al. 2006, Greenfield unpublished data). A leading hypothesis to explain this difference was that the fish, though similar in appearance, might have differing dietary exposures to Hg. Accordingly, I examined 10 specimens of each species from each of three sampling sites (China Camp, Newark Slough, and Eden Landing) visited over the last two years. I also include (in Table 5, Figure 1, and Appendices A and B) data from a single topsmelt from Oakland Middle Harbor, which I had examined during the planning phase of the laboratory work. All samples were from 2006 except that of China Camp topsmelt, which was taken in 2007. The fish ranged from 28 to 101 mm TL, and the samples were closely, but imperfectly matched in size (Figure 3).

As stated above, the diets of topsmelt and silverside were surprisingly similar (PSI=81%). Both species overall fed most heavily on corophiid amphipods (Table 5 and Appendix B), although this pattern was spatially inconsistent for silverside, which at Newark Slough fed mainly on cumaceans ("crustacean 1"), and at Eden Landing preyed more on small copepods and insects than on amphipods (Figure 4). Differences in fish size do not provide consistent explanations for these exceptions. The diet of both species was more varied at Eden Landing than at the other sites, and the proportion of cumaceans in the diet was highest for both species at Newark Slough. These patterns, if repeated in future sampling events, might indicate site differences in prey availability.

Most of the insects eaten by both species were planthopper nymphs and adults, which are known to infest cordgrass that grows along the marsh creek banks. The only indication that either species had ventured from the creeks (where sampling occurred) onto the marsh plain (where Hg methylation might be enhanced) was the presence of the two dolichopodid larvae in one of the topsmelt specimens. Both species consumed a few adult flies, but this information is somewhat ambiguous, because of the mobility of these insects. Further progress on diet-related Hg exposure in these two species might be obtained by more site-specific sampling of various microhabitats within these marshes.

DISCUSSION

Diet Composition

It is not possible to determine the composition of fish diets with any great precision. Even if all the bits could be assigned to species and weighed, one would still have to make some assumptions about their rates of digestion and passage. Here I have made the explicit assumption that all the bits that could not be identified were simply the digested remains of the bits that could be identified. This assumption may never be quite correct, and even when it is, use of the data still demands either measurements or assumptions about the (relative) rates at which the various prey species are digested. Implicitly, I have assumed (wrongly, to be sure) that all items are digested at the same rate. Then there is the question of passage rates. Do indigestible parts such as polychaete setae travel through the gut at the same rate as the much softer tests of crustaceans or the ultimately soluble shells of clams? I have assumed that they do, but if they move faster or slower than other items, then both the frequency data (Appendix B) and the volume estimates are biased. Still, imagining the volume occupied by a worm that (often) is represented only by its setae is an exercise in which I can claim no great accuracy: only that it is probably closer to the truth than simply estimating the volume of the setae themselves.

A true mechanistic understanding of the food-chain pathway of contaminants will ultimately embrace the variability in time and space of both the prey choices of the fish and the contaminant concentrations in the prey. At present, though, it is sufficient to ask how well we can describe the average situation. To approach this question for the two species in this study that are commonly eaten by people, I present here a summary of some previous results for comparison to the present findings. These are the afore-mentioned study by Roberts et al. (2000), who examined "stomachs" from shiner perch and white croaker samples taken in May through August and November, 2000, and my own work based on entire gut tracts of fish taken from Oakland Middle Harbor in April and June 1999 (with Jodie Little, performed under a contract between Entrix and the Port of Oakland; Appendix C).

Shiner perch

Roberts et al. (2000) examined 65 shiner perch, which ranged from 10-15 cm TL except those from Redwood Creek, which were 8-12 cm TL. These samples contained mainly benthic crustaceans and bivalves, with the substantial addition of polychaetes at the San Pablo and San Leandro Bay sites (Figure 5). Their Oakland Inner Harbor sample contained mostly bivalves. In the Oakland Middle Harbor samples from 1999, of 91 shiner perch ranging from 4 cm to 14 cm TL, amphipods ranked first in volume in 60 (including 38 if the 61 fish in the 10-14 cm TL range). Harpacticoids were the second-most frequent category to rank first, even in the 10-14 cm fish, and mollusks never ranked first (Appendix C). In the present study, shiner perch guts had amphipods and polychaetes in about equal amounts, but with the addition of cumaceans ("crustacean 1"), the total consumption of benthic and epibenthic crustaceans exceeded that of any other food group (Figure 1 and Table 2).

With such variability, more sampling would be needed to define the average diet, but as an approximation, it does not seem too simplistic to say that shiner perch consumes mainly small benthic and epibenthic crustaceans, sometimes adding in, or even switching to, major portions of polychaetes and clams. Although a shiner perch will rarely eat a fish (Appendix C), this species generally feeds at a lower trophic level consisting of filter feeders, detritivores and micro-carnivores. (The appearance of "fish" in Figure 5 appears to be due to a single incidence where a "fish rib bone" constituted a major fraction of the contents of a nearly-empty stomach, a manifestation of the afore-mentioned problem with unweighted averages of percentage data).

White croaker

Roberts et al. (2000) examined 27 white croaker, which ranged from 20-30 cm except for the San Leandro Bay sample, which ranged from 12-14 cm TL. This size difference probably explains the prevalence of copepods and ostracods in the San Leandro Bay sample, as contrasted with the high average percent of decapod shrimp in the larger white croaker from other sites (Figure 6). The white croaker samples in the present study were all larger than the San Leandro Bay fish of Roberts et al., and they resembled the larger fish in the previous study in having an apparent preference for larger prey (Figure 2 and Table 4). While the South Bay and Oakland croakers in the present study had not eaten large amounts of shrimp, they did contain substantial portions of the predatory mollusk *Philine* spp. In contrast to these findings, the majority of the white croaker in the 1999 Middle Harbor study had polychaetes as their first-ranked food item (17 of 30 fish > 15 cm TL; Appendix C). One obvious difference in the collections was that the Middle harbor specimens were captured mainly in April, whereas the RMP collections were made mainly in summer. None of the few white croaker in the June 1999 sample had polychaetes as the number-one ranked prey. The polychaetes identified included deposit feeders as well as raptorial types. *Philine auriformis* was abundant in Middle Harbor in 1999, and was eaten in fair numbers by English sole (*Pleuronectes vetulus*), but was used very little by white croaker at that time. (The *Philine* spp. in the present study were not *P. auriformis*.) Curiously, five of the six white croaker sampled in June 1999 had macroalgae (coded as "other" in Appendix C) as their most abundant food item. The fish remains identified in the 1999 study included anchovy, a flat fish, and a larval goby, as well as unidentified fish.

Thus, while capable of capturing large, mobile prey, white croaker is very flexible and opportunistic in its food habits, which were summarized well by Love (1991) as follows: "small croakers feed on plankton, while ones larger than about 4 in. [10 cm] eat such animals as worms, shrimp, and small fish."

Topsmelt and Mississippi silverside

These two Atherinopsids, in the small size range studied here in and near marsh creeks in late summer and fall, both fed principally on benthic crustaceans, with some utilization of both insects and planktonic crustaceans. In Clear Lake, Mississippi silverside has been reported to be a plankton feeder (Wurtsbaugh and Li 1985), although it was put there originally to control a benthic midge larva (Cook and Moore 1970), which it did successfully. Pflieger (1975) reported that the food habits of Mississippi silverside in midwestern lakes were similar to those of brook silverside (*Labidesthes sicculus*), which switches from planktivory to a diet of insects as the young move inshore at the end of their first summer. Visintainer et al. (2006), in a study done in marsh creeks at China Camp, reported findings similar to the present study in that both topsmelt and Mississippi silverside ate mainly corophiid amphipods and cumaceans, with the slight difference that significant, though small, percentages of plant hoppers (insects) and copepods were found only in the silverside diet.

For the present, it seems best to assume that in the habitats of interest (San Francisco Bay salt marshes), silverside (an annual species) and young-of-the-year topsmelt are both principally benthic foragers, with some reliance on zooplankton and the insects associated with plants and algal mats.

Benthic vs. Water-Column Feeding

The available evidence suggests that none of the four species in this study relies to any great extent on pelagic prey, at least at the times and places where they were sampled.

Trophic Levels

The Hg TMDL for San Francisco Bay Staff Report (SFBRWQCB 2006) summarizes the EPA use of the trophic level concept as follows: "The relative location of a species in the food chain is called the trophic level... Trophic level 1 plants are consumed by trophic level 2 herbivores, which are consumed by trophic level 3 predators, which are then consumed by trophic level 4 predators." The Staff Report indicates shiner perch to be a level 3 predator and white croaker to be at level 4, based on literature reviewed in the RMP 1999 Fish Report (SFEI 1999). In a gross sense, given that the above definition of trophic level includes the word "relative", the findings reported here confirm the assumptions of the TMDL Staff Report, in that white croaker clearly feeds at a higher level on the food chain, as a rule, than does shiner perch. However, confirmation of an over-simplified model of trophic relationships is an unpromising way to understand contaminant concentration in fish.

The RMP 1999 Fish Report (SFEI 1999) suggested that trophic level, along with observed variation among sampling sites and species-specific effects of size and age, was a likely co-determinant of contaminant biomagnification. Trophic position shifts with increasing size of an organism. Wyatt (1976) wrote, "Examinations of the food lists given by many authors for different sizes of a particular fish species almost always indicate a decline with increasing predator size of the numbers of small organisms eaten, and a corresponding increase in the numbers of larger organisms. Nor is this phenomenon confined to fish." In funding the present study and others like it (Roberts et al. 2000, Greenfield 2002), the RMP is obviously looking to make progress in its ability to understand and model the trophic structure of the bay and its contribution to contaminant concentrations in key species in the diets of humans and wildlife. In this regard, the pioneering study of Roberts et al. (2000), in which some of the lower trophic levels were investigated for contaminant concentration, was a step in the right direction. In the future, though, it would be best to use such investigations to test, or confirm assumptions about the trophic-level similarities of such organisms as amphipods and isopods, rather than to incorporate our assumption of similarity into the sampling protocol.

RECOMMENDATIONS

Compared to fish consumption advisories, the task of linking sediment contaminant concentrations to human and wildlife health, as embedded in the TMDL documents cited here (SFRWQCB 2006, 2008), is extremely complex. In a similar context, State Water Board staff (SWRCB 2007) wrote, "A thorough understanding of fish communities, trophic structure and uptake, and the pollutant contribution from all sources must be assessed in order to quantifiably link sediment and fish tissue contaminant levels." I do not believe that a detailed description of the San Francisco Bay food web is a realistic goal, but I do think that a less simple approach to the trophic level concept in modeling bioaccumulation is within the grasp of current funding levels. In other words, rather than considering, e.g., both California halibut and white croaker to be top carnivores (trophic level 4), it might be useful to refine this somewhat to, say, level 4 for halibut and level 3.7 for white croaker. Progress toward this end can be made through a combination of further diet studies along with direct measurement of selected contaminant levels in important prey species and the sediment with which they are associated. From the information at hand, obvious candidates are crangonid shrimp, corophiid amphipods, *Nippoleucon*, and perhaps anchovy, *Philine* and certain polychaete species or genera. Species- and size-specific information would be most useful. Along with good estimates of dietary fraction, these data for key prey species could be used to estimate average number of trophic linkages between sediment and target fish species by using the "food chain multiplier" framework discussed in USEPA (2000).

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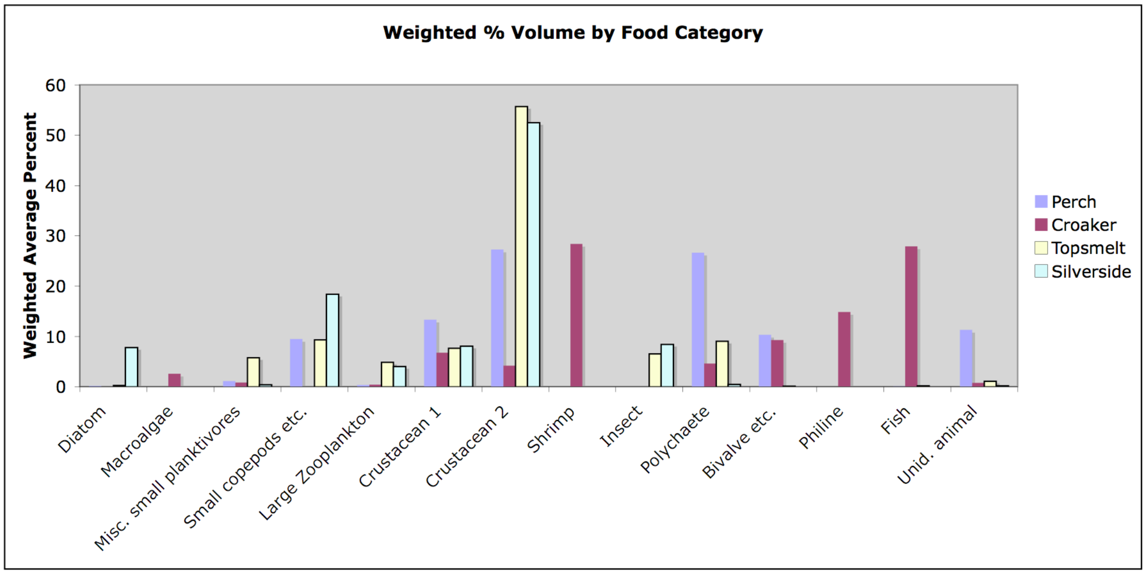


Figure 1. Weighted average percent volume of the 14 food categories in four fishes.

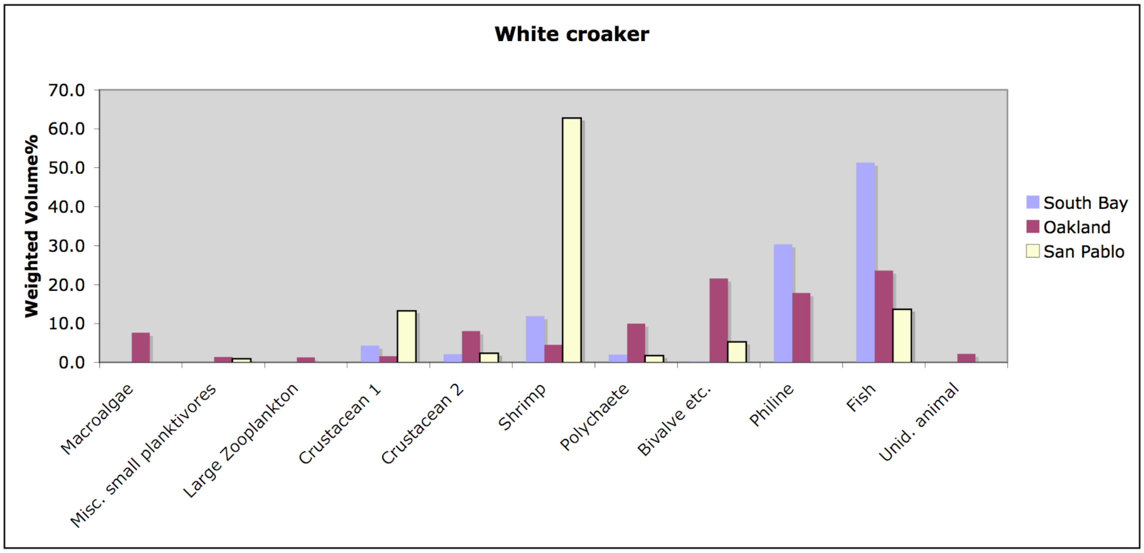


Figure 2. White croaker food category utilization at three sites.

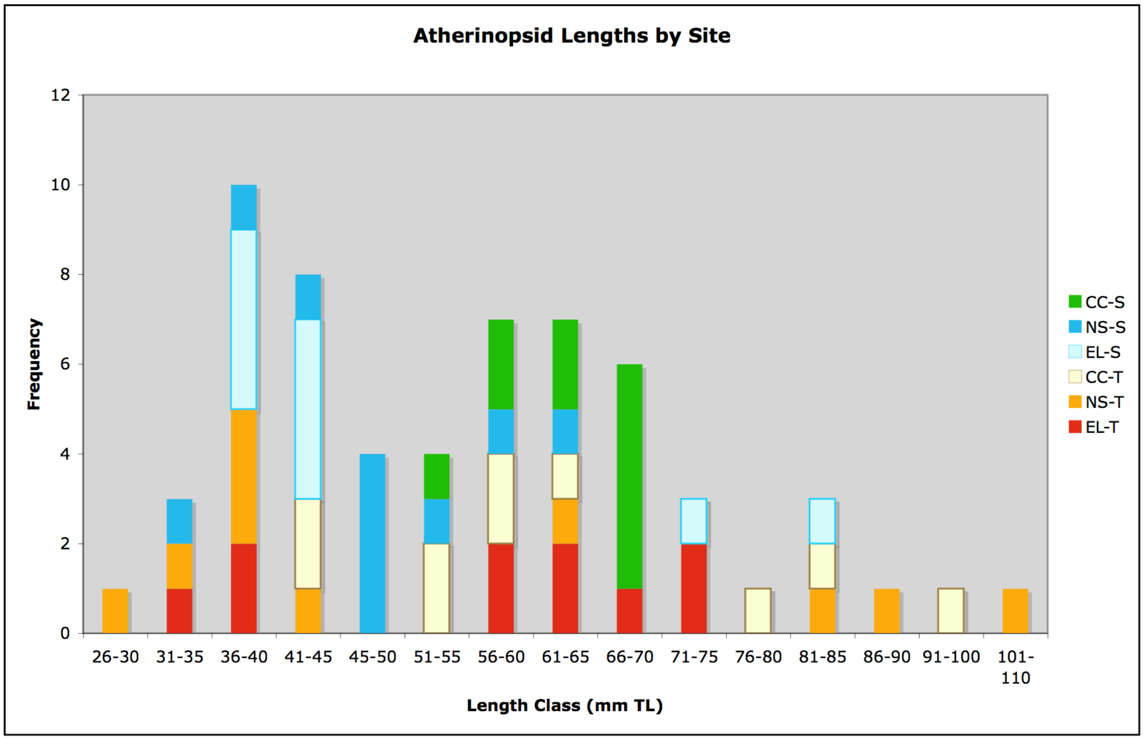


Figure 3. Combined length frequency plot of topsmelt (T, warm colors) and Mississippi silverside (S, blues and green) at three sites: China Camp (CC), Newark Slough (NS) and Eden Landing (EL).

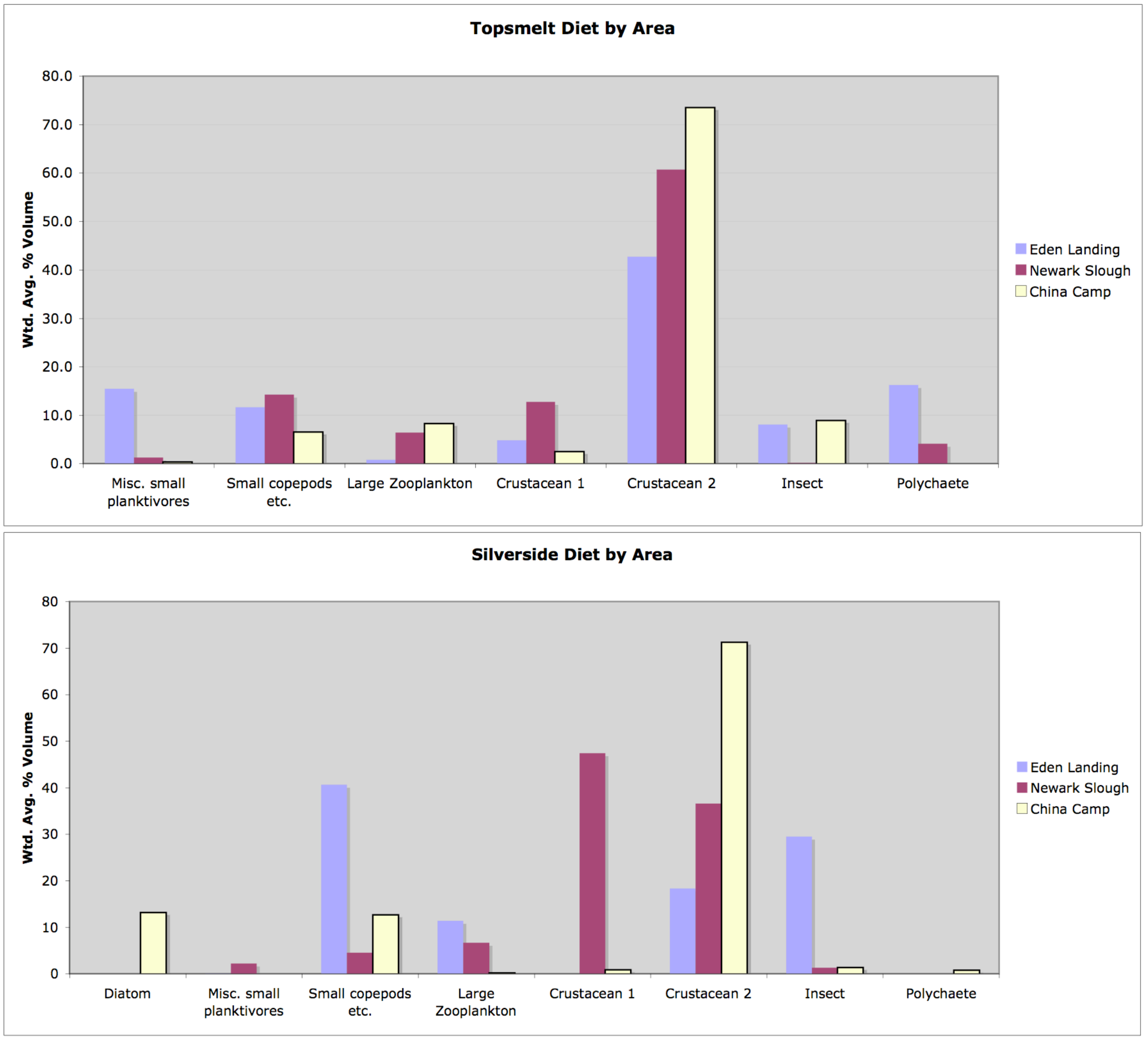
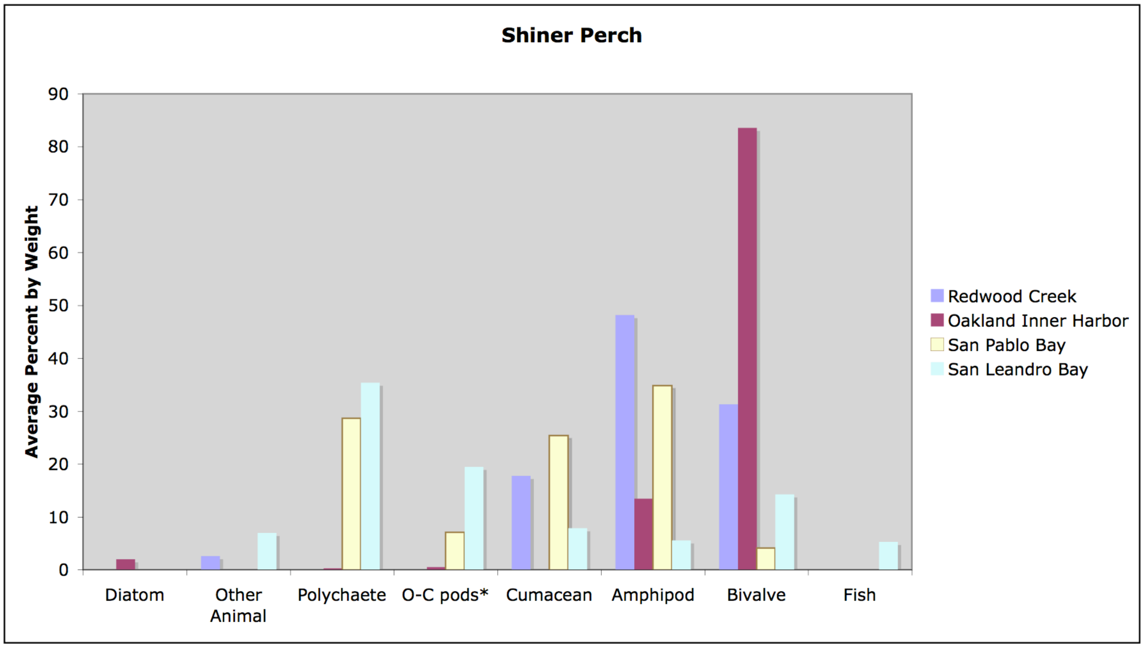
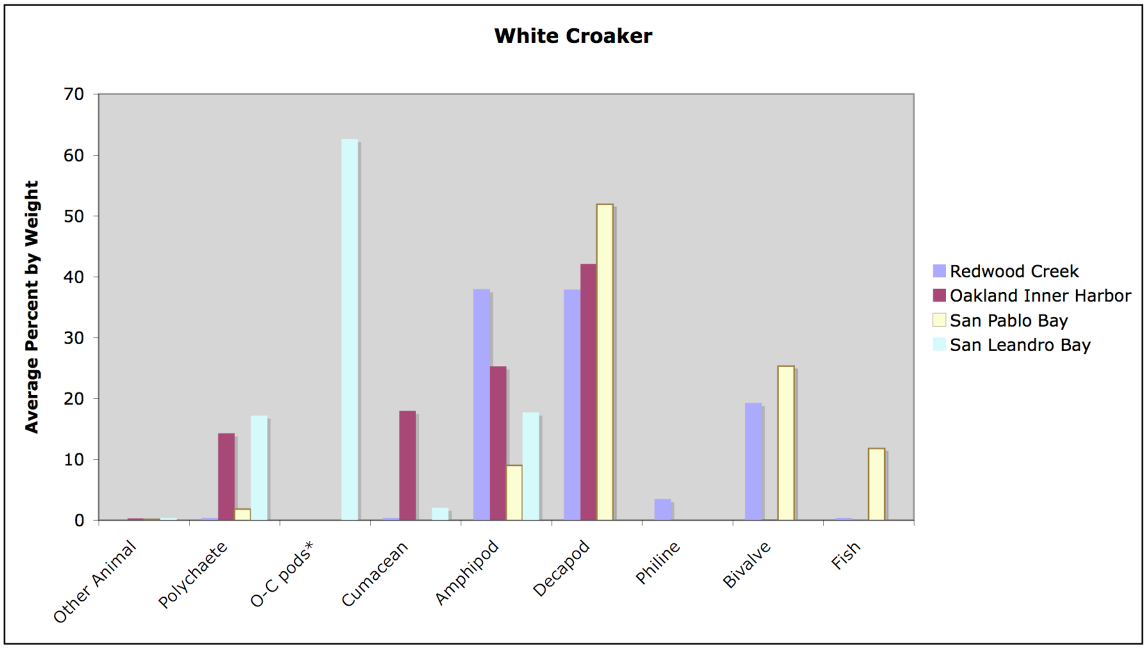


Figure 4. Weighted average percent volume of food categories at three sites for topsmelt (top panel) and Mississippi silverside.



*O-C pods = ostracods + copepods; the Amphipod category contains small percentages of isopods

Figure 5. Average percent by weight of food categories from shiner perch at four sites. Sample sizes varied from 13-19 fish per site; summarized from Roberts et al. (2000).



*O-C pods = ostracods + copepods; the Amphipod category contains small percentages of isopods

Figure 6. Average percent by weight of food categories from white croaker at four sites. Sample sizes varied from 5-9 fish per site; summarized from Roberts et al. (2000).

Table 2. Shiner perch summary

Food Category	Avg. %	Wtd. Avg. %
Diatom	0.1	0.1%
Macroalgae	0.0	0.0%
Misc. small planktivores	0.2	1.1%
Small copepods etc.	4.4	9.5%
Large Zooplankton	0.9	0.4%
Crustacean 1	7.9	13.3%
Crustacean 2	25.2	27.3%
Shrimp	0.0	0.0%
Insect	0.0	0.0%
Polychaete	23.7	26.6%
Bivalve etc.	6.7	10.3%
Philine	0.0	0.0%
Fish	3.4	0.1%
Unid. animal	9.7	11.3%

Table 3. Length (TL) data for 45 white croaker from three locations

Length (cm)	South Bay	Oakland	San Pablo
21-25	1	4	0
26-30	10	7	5
31-35	4	4	10

Table 4. White croaker summary

Food Category	Avg. %	Wtd. Avg. %
Diatom	0.0	0.0%
Macroalgae	3.3	2.6%
Misc. small planktivores	1.9	0.8%
Small copepods etc.	0.0	0.0%
Large Zooplankton	0.3	0.4%
Crustacean 1	4.2	6.8%
Crustacean 2	4.5	4.2%
Shrimp	25.9	28.4%
Insect	0.0	0.0%
Polychaete	8.0	4.6%
Bivalve etc.	7.7	9.3%
Philine	17.7	14.8%
Fish	18.4	27.9%
Unid. animal	0.9	0.7%

Table 5. Topsmelt and Silversde summary

	Topsmelt		Silverside	
Food Category	Avg. %	Wtd. Avg. %	Avg. %	Wtd. Avg. %
Diatom	0.1	0.2%	1.6	7.8%
Macroalgae	0.0	0.0%	0.0	0.0%
Misc. small planktivores	3.7	5.7%	0.7	0.4%
Small copepods etc.	34.2	9.3%	27.9	18.4%
Large Zooplankton	4.9	4.8%	6.4	4.0%
Crustacean 1	15.9	7.6%	18.4	8.0%
Crustacean 2	30.4	55.7%	32.7	52.5%
Shrimp	0.0	0.0%	0.0	0.0%
Insect	4.0	6.5%	11.5	8.4%
Polychaete	5.8	9.0%	0.3	0.4%
Bivalve etc.	0.2	0.0%	0.0	0.0%
Philine	0.0	0.0%	0.0	0.0%
Fish	0.1	0.1%	0.0	0.0%
Unid. animal	0.8	1.0%	0.4	0.2%

Appendix A: RMP Foodweb Analysis

Fish Specimen Information and Gut Contents Percent Volume by Food Category

Collection Date	Location	ID	Species	L(cm)	Mass (g)	Sex	Gut_mass (g)	Contents mass (g)	%Diatom	%Macro-algae	%Misc. small planktivores	%Small copepods etc.	%Large Zooplankton	%crustacean 1	%crustacean 2	% shrimp	% Insect	%poly-chaete	%Bivalve etc.	%Philine	%Fish	%Unid. animal
05/06	San Francisco Waterfront	06RMP050306F1T3201	Shiner Surfperch	12	39.57	F	NR	0.018						99					1			
05/06	Berkeley	06RMP050406F1T1201	Shiner Surfperch	11	17.52	F	0.227	0.065							100							
05/06	Oakland	06RMP050406F1T1206	Shiner Surfperch	11	20.17	F	0.271	0.109	5					5	40			50				
05/06	Oakland	06RMP050406F1T1207	Shiner Surfperch	13	36.39	F	0.226	0.161							60			40				
05/06	Oakland	06RMP050406F1T1210	Shiner Surfperch	12	25.20	F	0.299	0.205										50	50			
05/06	Oakland	06RMP050406F1T1212	Shiner Surfperch	14	44.05	F	0.665	0.110				10		35				5				50
05/06	South Bay	06RMP050406F1T2215	Shiner Surfperch	12	25.99	M	0.385	0.241						50					50			
06/06	South Bay	06RMP062006F2T2212	Shiner Surfperch	10	16.82	M	0.474	0.175						20				78	2			
06/06	South Bay	06RMP062006F2T2218	Shiner Surfperch	11	20.01	M	0.223	0.083										100				
06/06	South Bay	06RMP062006F2T2219	Shiner Surfperch	12	21.22	M	0.266	0.090											100			
06/06	Oakland	06RMP062006F2T3201	Shiner Surfperch	12	26.73	M	0.622	0.317														100
06/06	Waterfront	06RMP062006F2T3203	Shiner Surfperch	11	21.26	M	0.298	0.116										100				
06/06	San Francisco Waterfront	06RMP062006F2T4209	Shiner Surfperch	11	14.52	M	0.458	0.307				1		99								
07/07	Oakland Harbor	SPOAK2	Shiner Surfperch	12	NR	F	0.680	0.106							100							
07/07	Oakland Harbor	SPOAK5	Shiner Surfperch	14	NR	M	0.861	0.261							100							
07/07	Oakland Harbor	SPOAK9	Shiner Surfperch	12	NR	M	0.711	0.127							25			75				
07/07	Oakland Harbor	SPOAK24	Shiner Surfperch	13	NR	NR	0.683	0.048							75				25			
07/07	Oakland Harbor	SPOAK22	Shiner Surfperch	11	NR	NR	0.323	0.000														
07/07	Oakland Harbor	SPOAK13	Shiner Surfperch	12	NR	M	0.633	0.000														
07/07	Oakland Harbor	SPOAK19	Shiner Surfperch	11	NR	F	0.557	0.247			1			1	65			30			1	2
07/07	Oakland Harbor	SPOAK23	Shiner Surfperch	11	NR	NR	0.379	0.000														
07/07	Oakland Harbor	SPOAK7	Shiner Surfperch	10	NR	D	0.263	0.000														
07/07	Oakland Harbor	SPOAK10	Shiner Surfperch	12	NR	M	0.448	0.041										100				
07/07	Oakland Harbor	SPOAK8	Shiner Surfperch	12	NR	M	0.277	0.047										100				
07/07	Oakland Harbor	SPOAK17	Shiner Surfperch	13	NR	M	0.486	0.019							100							
07/07	Oakland Harbor	SPOAK11	Shiner Surfperch	12	NR	M	0.454	0.001													100	
07/07	Oakland Harbor	SPOAK6	Shiner Surfperch	12	NR	F	0.343	<.001						40					10		50	
07/07	Oakland Harbor	SPOAK16	Shiner Surfperch	12	NR	F	0.421	0.022					15									85
07/07	Oakland Harbor	SPOAK20	Shiner Surfperch	12	NR	M	0.374	0.000														
07/07	Oakland Harbor	SPOAK3	Shiner Surfperch	12	NR	F	0.452	0.000														
07/07	Oakland Harbor	SPOAK14	Shiner Surfperch	12	NR	M	0.390	0.000														
07/07	Oakland Harbor	SPOAK18	Shiner Surfperch	13	NR	M	0.507	0.030														100
07/07	Oakland Harbor	SPOAK21	Shiner Surfperch	11	NR	F	0.294	0.066					15		85							

Collection Date	Location	ID	Species	L(cm)	Mass (g)	Sex	Gut_mass (g)	Contents mass (g)	%Diatom	%Macro-algae	%Misc. small planktivores	%Small copepods etc.	%Large Zooplankton	%crustacean 1	%crustacean 2	% shrimp	% Insect	%poly-chaete	%Bivalve etc.	%Philine	%Fish	%Unid. animal
08/07	Bay	SPSLB27	Shiner Surfperch	9	NR	M	0.294	0.020														100
08/07	Bay	SPSLB3	Shiner Surfperch	14	NR	M	0.598	0.000							100							
08/07	Bay	SPSLB11	Shiner Surfperch	10	NR	NR	0.359	0.007					10	5	85							
08/07	Bay	SPSLB18	Shiner Surfperch	12	NR	F	0.402	0.124										100				
08/07	San Leandro Bay	SPSLB8	Shiner Surfperch	10	NR	M	0.270	0.007										100				
08/07	San Leandro Bay	SPSLB14	Shiner Surfperch	12	NR	F	0.566	0.204							90				10			
08/07	San Leandro Bay	SPSLB9	Shiner Surfperch	12	NR	F	0.417	0.071										90	10			
08/07	San Leandro Bay	SPSLB24	Shiner Surfperch	11	NR	F	0.355	0.071							10			50	40			
08/07	Bay	SPSLB13	Shiner Surfperch	10	NR	M	0.312	0.000003				100										
08/07	Bay	SPSLB2	Shiner Surfperch	14	NR	M	0.557	0														
08/07	Bay	SPSLB7	Shiner Surfperch	12	NR	F	0.355	0.002							100							
04/99	Oakland Harbor	MHEA 1999	Shiner Surfperch	12	15.18	F	0.697	0.423			10	85							5			
05/06	South Bay	06RMP050406F1T2101	White Croaker	29	358.33	M	2.385	0.364												100		
05/06	South Bay	06RMP050406F1T4101	White Croaker	27	234.48	M	1.940	0.815						90				5	5			
06/06	South Bay	06RMP061906F1T1101	White Croaker	32	402.72	M	3.531	1.466							10					90		
06/06	South Bay	06RMP061906F1T1102	White Croaker	30	354.12	F	1.630	0.276														
06/06	South Bay	06RMP062006F1T2101	White Croaker	27	331.04	M	2.442	0.852												100	100	
06/06	South Bay	06RMP062006F1T6101	White Croaker	24	170.13	M	2.238	0.724						10	20			20		30		
06/06	South Bay	06RMP062006F1T6102	White Croaker	29	332.12	F	5.948	2.003							5						95	
06/06	South Bay	06RMP062006F1T6103	White Croaker	29	313.24	M	3.941	1.253								25		5			70	
06/06	South Bay	06RMP062006F1T6104	White Croaker	28	349.86	M	11.140	6.546								10					90	
06/06	South Bay	06RMP062006F1T6105	White Croaker	33	435.40	F	5.135	0.717												100		
06/06	South Bay	06RMP062006F1T7101	White Croaker	26	245.87	M	0.900	0.167								100						
06/06	South Bay	06RMP062006F1T7102	White Croaker	31	361.32	M	2.756	0.974												100		
06/06	South Bay	06RMP062006F1T7103	White Croaker	30	295.19	M	2.301	0.392								100						
06/06	South Bay	06RMP062006F1T7104	White Croaker	26	243.80	F	3.206	0.686								100						
06/06	South Bay	06RMP062006F1T7105	White Croaker	33	334.12	M	4.223	1.331										10		90		
06/06	Oakland	06RMP062106F2T2101	White Croaker	29	350.25	M	4.423	2.190								15		4	1		80	
06/06	Oakland	06RMP062106F2T2102	White Croaker	29	281.63	F	5.052	1.189							5	5			10	80		
06/06	Oakland	06RMP062106F2T2103	White Croaker	29	275.47	M	3.010	1.292						5	15			25	25			30
06/06	Oakland	06RMP062106F2T2104	White Croaker	28	275.10	M	4.496	1.915		25			15	15	15				30			
06/06	Oakland	06RMP062106F2T2105	White Croaker	23	155.63	F	5.088	3.081							10			10	5	75		
07/06	Oakland	06RMP070606F2T1101	White Croaker	21	103.22	M	3.797	1.953							20			40	25	15		
07/06	Oakland	06RMP070606F2T1102	White Croaker	22	137.85	M	3.724	1.972							10	5		20	60		5	
07/06	Oakland	06RMP070606F2T1103	White Croaker	24	183.80	M	1.750	0.745			5				15			20	60			

Collection Date	Location	ID	Species	L(cm)	Mass (g)	Sex	Gut_mass (g)	Contents mass (g)	%Diatom	%Macro-algae	%Misc. small planktivores	%Small copepods etc.	%Large Zooplankton	%crustacean 1	%crustacean 2	% shrimp	% Insect	%poly-chaete	%Bivalve etc.	%Philine	%Fish	%Unid. animal
07/06	Oakland	06RMP070606F2T1104	White Croaker	26	237.43	M	5.596	1.928							5	25		5	50	15		
07/06	Oakland	06RMP070606F2T1105	White Croaker	27	248.13	M	6.796	2.936							3				12		85	
08/06	Oakland	06RMP081606F2T1101	White Croaker	30	278.46	M	2.089	1.092		100												
08/06	Oakland	06RMP081606F2T2101	White Croaker	31	334.21	M	2.865	0.000														
08/06	Oakland	06RMP081606F2T2102	White Croaker	32	408.88	F	1.947	0.327		25	70								5			
08/06	Oakland	06RMP081606F2T2103	White Croaker	34	419.67	F	2.401	0.861			5										85	10
08/06	Oakland	06RMP081606F2T2104	White Croaker	31	331.06	M	1.774	0.000														
05/06	San Pablo Bay	06RMP052306F5H1101	White Croaker	28	276.27	M	6.681	2.315							5	60			35			
05/06	San Pablo Bay	06RMP052306F5H1102	White Croaker	31	369.97	F	10.200	3.606							5	85			10			
05/06	San Pablo Bay	06RMP052406F5H1101	White Croaker	30	356.81	F	9.949	4.524			5			70	5	20						
08/06	San Pablo Bay	06RMP081706F5G2101	White Croaker	29	317.29	M	5.187	0.583							5	80			15			
08/06	San Pablo Bay	06RMP081706F5G2102	White Croaker	28	264.73	F	4.006	0.724								100						
08/06	San Pablo Bay	06RMP081706F5G1101	White Croaker	31	433.96	M	.	1.660													100	
08/06	San Pablo Bay	06RMP081706F5G1102	White Croaker	31	397.17	M	1.398	0.340								100						
08/06	San Pablo Bay	06RMP081706F5G1103	White Croaker	33	478.98	M	3.310	0.184										100				
08/06	San Pablo Bay	06RMP081706F5G1104	White Croaker	33	450.59	M	3.277	1.065													100	
08/06	San Pablo Bay	06RMP081706F5G1105	White Croaker	34	514.17	M	4.755	2.624								80					20	
08/06	San Pablo Bay	06RMP081706F5G1106	White Croaker	32	542.85	F	10.165	3.764								100						
08/06	San Pablo Bay	06RMP081706F5G1107	White Croaker	32	415.71	F	3.739	0.452								50		50				
08/06	San Pablo Bay	06RMP081706F5G1108	White Croaker	33	501.05	F	6.341	0.000														
08/06	San Pablo Bay	06RMP081706F5G1109	White Croaker	29	332.03	F	4.226	0.025							50	5		45				
08/06	San Pablo Bay	06RMP081706F5G2103	White Croaker	31	439.69	F	8.711	2.012								100						
05/06	Oakland Harbor	OAK1	Topsmelt	7.0	1.944	NR	0.138	0.081	3					40				40			2	15
09/06	Eden Landing	EL1	Topsmelt	3.3	NR	NR	0.009	0.001				100										
09/06	Eden Landing	EL2	Topsmelt	3.6	0.233	NR	NR	0.001			40	50			5							5
09/06	Eden Landing	EL3	Topsmelt	3.6	0.231	NR	NR	0.001				95	2		1							2
09/06	Eden Landing	EL4	Topsmelt	6.0	1.244	NR	NR	0.001				91	8									1
09/06	Eden Landing	EL5	Topsmelt	6.0	1.096	M	NR	0.140			15	15		15			25	30				
09/06	Eden Landing	EL6	Topsmelt	6.3	1.185	F	0.081	0.031			3	3	3					90				1
09/06	Eden Landing	EL7	Topsmelt	6.4	1.250	M	NR	0.025				90	9									1
09/06	Eden Landing	EL8	Topsmelt	6.6	1.466	M	0.092	0.072			1				99							
09/06	Eden Landing	EL9	Topsmelt	7.1	1.738	F	NR	0.050				5			95							
09/06	Eden Landing	EL10	Topsmelt	7.4	2.104	M	0.135	0.109			40				60							
09/06	Newark Slough	NEW-1	Topsmelt	10.1	5.785	M	NR	0.010				50	5	40	5							
09/06	Newark Slough	NEW-2	Topsmelt	8.6	3.062	M	0.189	0.133							100							
09/06	Newark Slough	NEW-3	Topsmelt	8.2	2.500	M	0.114	0.046			5	40	30	5				20				
09/06	Newark Slough	NEW-4	Topsmelt	6.3	1.082	M	0.037	0.013			4	2		85	5				4			
09/06	Newark Slough	NEW-5	Topsmelt	4.0	0.315	NR	0.009	0.002				95		5								
09/06	Newark Slough	NEW-6	Topsmelt	4.1	0.303	F	0.011	0.004				90		8					2			
09/06	Newark Slough	NEW-7	Topsmelt	4.0	0.333	M	0.011	0.007				20		75	5							
09/06	Newark Slough	NEW-8	Topsmelt	3.7	0.239	F	0.005	0.003				40		50	6		4					

Collection Date	Location	ID	Species	L(cm)	Mass (g)	Sex	Gut_mass (g)	Contents mass (g)	%Diatom	%Macro-algae	%Misc. small planktivores	%Small copepods etc.	%Large Zooplankton	%crustacean 1	%crustacean 2	% shrimp	% Insect	%poly-chaete	%Bivalve etc.	%Philine	%Fish	%Unid. animal
09/06	Newark Slough	NEW-9	Topsmelt	3.1	0.161	F	0.007	0.005				1		80	15		4					
09/06	Newark Slough	NEW-10	Topsmelt	2.8	0.120	NR	0.001	<.001				70		30								
10/07	China Camp	TCC1	Topsmelt	9.1	3.358	F	0.204	0.139							100							
10/07	China Camp	TCC2	Topsmelt	8.4	2.806	M	0.144	0.105			1			1	98							
10/07	China Camp	TCC3	Topsmelt	7.6	1.980	M	0.076	0.039							100							
10/07	China Camp	TCC4	Topsmelt	6.1	1.069	M	0.055	0.040							85		15					
10/07	China Camp	TCC5	Topsmelt	6.0	1.082	F	0.083	0.067					10		60		30					
10/07	China Camp	TCC6	Topsmelt	5.9	0.992	M	0.061	0.041				53	7				40					
10/07	China Camp	TCC7	Topsmelt	5.5	0.744	M	0.034	0.015				15		40	45							
10/07	China Camp	TCC8	Topsmelt	5.3	0.810	F	0.055	0.045					70	10	15		5					
10/07	China Camp	TCC9	Topsmelt	4.4	0.415	F	0.025	0.010			5	75	5	10	5							
10/07	China Camp	TCC10	Topsmelt	4.3	0.349	F	0.012	0.002				60	2		38							
09/06	Eden Landing	EL-M1	Mississippi silverside	3.8	0.210	M	0.005	0.001				60	40									
09/06	Eden Landing	EL-M2	Mississippi silverside	3.7	0.223	F	0.009	0.005				95	5									
09/06	Eden Landing	EL-M3	Mississippi silverside	4.2	0.276	M	0.012	0.005				5					95					
09/06	Eden Landing	EL-M4	Mississippi silverside	3.7	0.213	M	0.007	0.001				95					5					
09/06	Eden Landing	EL-M5	Mississippi silverside	4.0	0.266	F	0.008	0.003				40					60					
09/06	Eden Landing	EL-M6	Mississippi silverside	4.2	0.308	M	0.013	0.005				60					40					
09/06	Eden Landing	EL-M7	Mississippi silverside	4.4	0.336	M	0.011	0.003			3	95					2					
09/06	Eden Landing	EL-M8	Mississippi silverside	4.5	0.355	M	0.022	0.012				10			15		75					
09/06	Eden Landing	EL-M9	Mississippi silverside	7.2	1.407	F	0.065	0.034				70	30									
09/06	Eden Landing	EL-M10	Mississippi silverside	8.3	1.977	F	0.054	0.026							60		40					
09/06	Newark Slough	NEW-M1	Mississippi silverside	6.2	0.884	F	0.022	0.015				5		45	50							
09/06	Newark Slough	NEW-M2	Mississippi silverside	5.8	0.791	M	0.021	0.008				4		1	95							
09/06	Newark Slough	NEW-M3	Mississippi silverside	5.4	0.578	F	0.015	0.005				5	50	45								
09/06	Newark Slough	NEW-M4	Mississippi silverside	4.7	0.417	F	0.013	0.008			17	5		10	55		10					3
09/06	Newark Slough	NEW-M5	Mississippi silverside	4.6	0.409	M	0.011	0.006				5	5	80	10							
09/06	Newark Slough	NEW-M6	Mississippi silverside	4.9	0.430	F	0.008	0.002				10	50	20	20							
09/06	Newark Slough	NEW-M7	Mississippi silverside	4.6	0.367	M	0.007	0.004				4		80	6							10
09/06	Newark Slough	NEW-M8	Mississippi silverside	4.4	0.359	F	0.008	0.003						85	15							
09/06	Newark Slough	NEW-M9	Mississippi silverside	3.3	0.220	F	0.008	0.007				5		85	10							
09/06	Newark Slough	NEW-M10	Mississippi silverside	3.8	0.271	F	0.004	0.002					10	85	5							
09/06	China Camp	MCC1	Mississippi silverside	5.7	0.880	M	0.031	0.015							100							
09/06	China Camp	MCC2	Mississippi silverside	6.8	1.236	NR	0.037	0.013						4	96							
09/06	China Camp	MCC3	Mississippi silverside	7.0	1.302	M	0.049	0.020							100							
09/06	China Camp	MCC4	Mississippi silverside	5.7	0.771	F	0.027	0.017				68		2	5		15	10				
09/06	China Camp	MCC5	Mississippi silverside	6.3	0.874	F	0.016	0.006				50			50							
09/06	China Camp	MCC6	Mississippi silverside	6.4	0.884	M	0.025	0.014				50			50							

Collection Date	Location	ID	Species	L(cm)	Mass (g)	Sex	Gut_mass (g)	Contents mass (g)	%Diatom	%Macro-algae	%Misc. small planktivores	%Small copepods etc.	%Large Zooplankton	%crustacean 1	%crustacean 2	% shrimp	% Insect	%poly-chaete	%Bivalve etc.	%Philine	%Fish	%Unid. animal
09/06	China Camp	MCC7	Mississippi silverside	6.8	1.605	M	0.105	0.060	49			1			50							
09/06	China Camp	MCC8	Mississippi silverside	6.8	1.290	F	0.038	0.025					1	3	95		1					
09/06	China Camp	MCC9	Mississippi silverside	5.1	0.498	M	0.011	0.004				90	1	7			2					
09/06	China Camp	MCC10	Mississippi silverside	7.0	1.661	M	NR	0.050				5			95							

Key for Appendix A

Food Category	Comment	(See Appendix B for exact designations)
None	organic matter not considered a source of nutriment	
Diatom		
Macroalgae		
Misc. small planktivc	presumed consumers of phytoplankton and microzooplankton	
Small copepods etc.	Planktonic and epibenthic crustaceans <1 mm body length (BL), mainly harpacticoids <0.5 mm BL	
Large Zooplankton	Planktonic copepods >0.5 mm prosome length and other planktonic crustaceans >1 mm BL	
Crustacean 1	Nippoleucon himumensis (a cumacean) and other benthic and epibenthic crustaceans <3mm BL	
Crustacean 2	Gammarid amphipods and other benthic and epibenthic crustaceans generally > 3mm BL	
Shrimp	Adult and subadult Crangon spp.	
Insect	Adult and larval Hemiptera, Diptera, and (possibly) Coleoptera	
Polychaete	Polychaetes and oligochaetes	
Bivalve etc.	Molluscs, mainly clams and mussels	
Philine	A clam predator, the slug Philine auriformis	
Fish	Fish (mainly northern anchovy), fish eggs, and fish scales	
Unid. animal		

Appendix B. RMP Foodweb Analysis. Frequency of Occurrence of Food Items in Four Fish Species

					Shiner perch		**White croaker**		**Topsmelt**		**Mississippi silverside**	
		Number empty			**8**		**3**		**0**		**0**	
		number non-empty			**37**		**42**		**31**		**30**	
taxon_code	Major Group	Category or Item name	Food Code	Food Category	occurrences as ranked item	occurrences in trace quantity	occurrences as ranked item	occurrences in trace quantity	occurrences as ranked item	occurrences in trace quantity	occurrences as ranked item	occurrences in trace quantity
1	Unknown	unid. object	0	None					2		2	
11	Diatoms	pennate diatom	1	Diatom							1	
12	Diatoms	centric diatom	1	Diatom	1					4		5
21	Green algae	green filamentous alga	2	Macroalgae			2					
25	Red algae	red foliose alga	2	Macroalgae			1					
40	Vascular plant	Vascular plant	0	None								
41	Vascular plant	unid. seed	0	None				1				1
45	Vascular plant	unid. wood frag.	0	None				2				1
51	Protozoa	unid. foraminiferan	3	Misc. microplanktivores		2			1		1	
52	Protozoa	unid. tintinnid	3	Misc. microplanktivores					1		1	1
99	Animalia	unid. animal	14	Unid. Animal	6		2				1	
99.9	Animalia	invertebrate egg	14	Unid. Animal								
101	Hydrozoa	unid. hydroid	3	Misc. microplanktivores	1	2	4	9	7	6	2	
105	Hydrozoa	unid octocoral(?)	3	Misc. microplanktivores								
200	Rotifera	Rotifer	3	Misc. microplanktivores								1
300	Polychaeta	Polychaete	10	Polychaete	17		13	3	4		1	
410	Ostracoda	Ostracod	4	Small copepods etc.	2	5			3	2	1	1
422	Copepoda	large calanoid	5	Large Zooplankton					5		6	
423	Copepoda	Coullana sp.	6	Crustacean 1	2				1			
424	Copepoda	unid. large harpacticoid	6	Crustacean 1							1	1
426	Copepoda	large cyclopoid	5	Large Zooplankton	2			1				
428	Copepoda	small harpacticoids et al.	4	Small copepods etc.	2			1	22		23	1
432	Cirripedia	Cyprid larva	5	Large Zooplankton						1	1	2
440	Mysidacea	unid. mysid	5	Large Zooplankton	1		1		2			
441	Mysidacea	Neomysis sp.	5	Large Zooplankton					1			
442	Mysidacea	Neomysis japonica	5	Large Zooplankton					1			
450	Cumacea	Nippoleucon hinumensis	6	Crustacean 1	9	2	5	3	13	1	13	1
462	Isopoda	Synidotea harfordi	7	Crustacean 2			3					
463	Isopoda	S. laticauda	7	Crustacean 2			2		4		2	
465	Isopoda	Idoteidae	7	Crustacean 2			1					
469	Isopoda	unid. isopod	7	Crustacean 2			1		1		1	1
470	Tanaidacea	unid. tanaid	7	Crustacean 2					1			
471	Tanaidacea	Pancolus californiensis	7	Crustacean 2							1	
472	Tanaidacea	Sinelobus sp.	7	Crustacean 2					1			
480.5	Amphipoda	Americorophium stimpsoni	7	Crustacean 2					1			
481	Amphipoda	Corophium aliense	7	Crustacean 2					4		8	
482	Amphipoda	Corophium heteroceratum	7	Crustacean 2			5					
483	Amphipoda	unid. corophiid	7	Crustacean 2	8	1	2		9		12	

					Shiner perch		White croaker		Topsmelt		Mississippi silverside	
		Number empty			8		3		0		0	
		number non-empty			37		42		31		30	
taxon_code	Major Group	Category or Item name	Food Code	Food Category	occurrences as ranked item	occurrences in trace quantity	occurrences as ranked item	occurrences in trace quantity	occurrences as ranked item	occurrences in trace quantity	occurrences as ranked item	occurrences in trace quantity
484	Amphipoda	Grandidierella japonica	7	Crustacean 2					2			
488	Amphipoda	Ampelisca sp.	7	Crustacean 2	1		2	2	1			
488.5	Amphipoda	Pleustidae	7	Crustacean 2					1			
489	Amphipoda	unid. gammarid	7	Crustacean 2	2	1	4	1	10		5	2
491	Amphipoda	Caprella californica	7	Crustacean 2				1				
492	Amphipoda	Deutella californica	7	Crustacean 2					1			
493	Amphipoda	unid. caprellid	7	Crustacean 2			1		1			
501	Decapoda	Crangon franciscorum	8	Shrimp			10					
502	Decapoda	Crangon nigricauda	8	Shrimp			3					
503	Decapoda	Crangon sp.	8	Shrimp			11					
504	Decapoda	Crangon zoea stage 1&2	5	Large Zooplankton					3	1	2	
600	Crustacea	unid. crustacean	7	Crustacean 2	11				2	1		
700	Insecta	Hemiptera	9	Insect								
710	Insecta	unid. planthopper	9	Insect					6		9	2
712	Insecta	unid. scale	9	Insect							1	
720	Insecta	Diptera	9	Insect								
721	Insecta	unid. fly adult	9	Insect							4	
722	Insecta	unid dipteran larva	9	Insect					1			
725	Insecta	Dolichopodid larva	9	Insect					1			
750	Insecta	unid. insect	9	Insect					1	1	1	
801	Gastropoda	unid. snail/veliger	11	Bivalve					2			
850	Gastropoda	Philine sp.	12	Philine			11					
901	Bivalvia	Mytilus sp.	11	Bivalve			2					
904	Bivalvia	Musculista senhousia	11	Bivalve			3					
909	Bivalvia	unid. mytilid	11	Bivalve			4	1	1			
920	Bivalvia	Macoma sp.	11	Bivalve			4					
930	Bivalvia	Theora sp.	11	Bivalve	3		4					
940	Bivalvia	unid. clam	11	Bivalve	5	2	6	2	1	1		
990	Mollusca	unid. mollusc	11	Bivalve	1	1						
1000	Bryozoa	Bryozoan	3	Misc. microplanktivores				2	3	1		
1210	Vertebrata	northern anchovy	13	Fish			6					
1211	Vertebrata	n. anchovy egg	13	Fish	1							
1230	Vertebrata	jacksmelt egg mass	13	Fish			1					
1299	Vertebrata	unid. fish	13	Fish			4					
1300	Vertebrata	unid. fish scale	13	Fish	2	1		1				
1500	Vertebrata	unid. feather	0	None								

Appendix C. 1999 Fish feeding study, Oakland Middle Harbor. Food categories ranked by apparent volume

survey	week	Day(D)/ Night(N)	< 6m (S)/ >6m (D)	SPECIES	id#	SL (mm)	TL (cm)	mass (g)	stomach fullness	pelag. fish	Bottom fish	unid. fish	shrimp	mollusk	amphipod	other benth. crust.	mysid	unid. crust	plankt. copepod	harpacticoid copepod	annelid	barnacle cypris larva	other
June	1	D	S	Shiner surfperch	13	33	4	0.9	0														
June	2	D	S	Shiner surfperch	25	34	4	1	3						1								
June	1	D	D	Shiner surfperch	7	36	5	0.8	1									2				1	
June	1	D	S	Shiner surfperch	12	36	5	1	1										1				
June	2	D	S	Shiner surfperch	14	37	5	1.2	2						1								
June	2	D	S	Shiner surfperch	20	37	5	1.2	2						1								
June	2	D	S	Shiner surfperch	22	37	5	1.1	2						1								
June	1	D	D	Shiner surfperch	6	38	5	1.4	1						1							2	
June	2	D	S	Shiner surfperch	18	38	5	1.2	1						1						2		
June	2	D	S	Shiner surfperch	26	38	5	1.2	2						1								
June	2	D	S	Shiner surfperch	27	38	5	1.2	3						1								
June	2	D	S	Shiner surfperch	19	39	5	1.6	3						1				3				
June	2	D	S	Shiner surfperch	13	40	5	1.8	3						1								
June	2	D	S	Shiner surfperch	21	40	5	1.7	3						1	2					3		
June	2	D	S	Shiner surfperch	23	40	5	1.2	1						1								
June	2	D	S	Shiner surfperch	17	41	5	1.8	2						1								
June	2	D	S	Shiner surfperch	16	42	5	1.7	4						1								
June	2	D	S	Shiner surfperch	24	42	5	1.6	2						1								
June	2	D	S	Shiner surfperch	15	43	5	1.8	4						1								
June	1	D	S	Shiner surfperch	14	45	6	1.4	3						1	2							
June	1	D	D	Shiner surfperch	5	46	6	2.5	4										1			2	
June	2	D	S	Shiner surfperch	10	46	6	2.7	3										2				
June	2	D	D	Shiner surfperch	3	47	6	3.4	1														
June	2	D	S	Shiner surfperch	9	48	6	3.7	3						1								
June	2	D	S	Shiner surfperch	11	48	6	2.3	1						1								
June	2	D	S	Shiner surfperch	12	48	6	2.3	4						1								
June	1	D	S	Shiner surfperch	11	52	7	2.7	1						1								
June	2	D	D	Shiner surfperch	2	58	7	5.2	2						2								
June	2	D	S	Shiner surfperch	8	74	9	10.7	4						1								
April	2	D	D	Shiner perch	5	75	9	11.2	5											1			2
April	2	D	D	Shiner perch	1	76	10	14.7	4						3					1	4		2
April	1	D	S	Shiner perch	4	79	10	10.6	4						1								
April	2	N	S	Shiner perch	2	79	10	11.9	4						1								
June	1	D	S	Shiner surfperch	6	79	10	13.4	5						1								
April	1	D	D	Shiner perch	7	80	10	13.4	4						1	2					3		
April	2	N	D	Shiner perch	4	80	10	16.1	3							3				1			2
April	1	N	D	Shiner perch	2	81	10	16	2						1								
April	1	D	D	Shiner perch	8	81	10	12	4						4	2				1	3		
June	1	D	S	Shiner surfperch	5	81	10	12.9	3						1								
April	1	D	D	Shiner perch	4	82	10	17	5					3	1	2							
April	2	N	D	Shiner perch	3	82	10	18	4						2	4				1	3		
April	2	D	D	Shiner perch	6	82	10	16.8	5							3				1			2
June	1	D	S	Shiner surfperch	4	82	10	12.7	2						1								
June	1	D	S	Shiner surfperch	9	82	10	13.6	2			4			1						2		
April	1	N	D	Shiner perch	1	83	10	17	0						1								
April	1	D	D	Shiner perch	2	83	10	15	3									1					
April	2	N	D	Shiner perch	2	83	10	17.6	0									1					
June	1	D	S	Shiner surfperch	7	83	10	15.2	5						1	2							
April	1	N	S	Shiner perch	6	85	11	21	1						1								

survey	week	Day(D)/ Night(N)	< 6m (S)/ >6m (D)	SPECIES	id#	SL (mm)	TL (cm)	mass (g)	stomach fullness	pelag. fish	Bottom fish	unid. fish	shrimp	mollusk	amphipod	other benth. crust.	mysid	unid. crust	plankt. copepod	harpacticoid copepod	annelid	barnacle cypris larva	other
April	1	D	D	Shiner perch	5	85	11	15.7	3					5	2	3				4	1		
April	2	N	D	Shiner perch	5	87	11	19.8	2					1	4	2					3		5
June	1	D	D	Shiner surfperch	3	87	11	16.5	3							1		2					
April	2	N	D	Shiner perch	1	88	11	21	0							4				1	2		3
April	2	N	S	Shiner perch	1	88	11	14.3	4						1	3				4			2
April	1	N	S	Shiner perch	7	90	11	20	1						1								
April	1	N	S	Shiner perch	9	90	11	17.2	1						1	3				2			4
June	1	D	S	Shiner surfperch	3	90	11	18.7	4					3	1								
June	1	D	S	Shiner surfperch	8	90	11	19.4	2						1								
June	1	D	D	Shiner surfperch	4	91	11	18.6	4					3	1	2							
June	1	D	S	Shiner surfperch	2	91	11	22	5						1								
June	1	D	S	Shiner surfperch	10	91	11	25	5						1								
April	1	D	S	Shiner perch	2	92	12	20	3					2	1								
April	1	N	S	Shiner perch	10	92	12	19.2	1					2	1								
June	2	D	S	Shiner surfperch	7	92	12	19.9	1						1								
April	2	D	D	Shiner perch	3	93	12	23	5									3		1			2
June	2	D	S	Shiner surfperch	6	93	12	19.7	3					2	1								
April	1	N	S	Shiner perch	4	94	12	23	2					2	1								
April	1	D	D	Shiner perch	9	94	12	18.1	2						1	2					3		
June	2	D	S	Shiner surfperch	2	94	12	21	0														
April	1	D	D	Shiner perch	10	95	12	21	3					2	5	3				1	4		6
April	1	D	S	Shiner perch	3	95	12	22	4						1								
June	2	D	S	Shiner surfperch	5	96	12	21	4						1								
April	1	N	S	Shiner perch	5	98	12	27	2						1								
April	1	D	S	Shiner perch	5	98	12	28	1						1								
April	2	D	D	Shiner perch	2	98	12	21	5						3	4				1			2
June	1	D	D	Shiner surfperch	2	99	12	22	0														
April	1	N	S	Shiner perch	8	100	13	27	1						1								
April	1	D	D	Shiner perch	3	100	13	28	4						3	2					1		
June	1	D	S	Shiner surfperch	1	100	13	26	3						1								
April	1	D	S	Shiner perch	1	101	13	27	2						1								
April	2	D	D	Shiner perch	4	101	13	29	5						3	1					2		
June	2	D	D	Shiner surfperch	1	102	13	34	1														
April	1	D	D	Shiner perch	1	104	13	28	4					3	1			2					
April	1	N	S	Shiner perch	1	105	13	31	2						2						1		
June	2	D	S	Shiner surfperch	3	106	13	28	3						1								
April	1	N	S	Shiner perch	2	107	13	35	2						1								
April	1	N	S	Shiner perch	3	109	14	36	0									1					
April	1	D	D	Shiner perch	6	109	14	28	3							1					2		
June	2	D	S	Shiner surfperch	1	111	14	27	1						1								
June	1	D	D	Shiner surfperch	1	113	14	41	0														
June	2	D	S	Shiner surfperch	4	115	14	36	3						1								
April	2	D	D	White croaker	8	86	10	15.3	5						2						1		
April	1	D	D	White croaker	6	91	11	17	3						3					1	2		
April	1	D	D	White croaker	5	92	11	18	5					1	3	4			5		2		
June	1	D	D	White croaker	3	102	12	21	3					5	4				2		3		1
April	1	D	D	White croaker	1	108	13	25	5		1								2	3	4		
June	1	D	D	White croaker	2	145	17	53	4					1		4		2					3
April	1	D	D	White croaker	3	133	16	54	3						2						1		

survey	week	Day(D)/ Night(N)	< 6m (S)/ >6m (D)	SPECIES	id#	SL (mm)	TL (cm)	mass (g)	stomach fullness	pelag. fish	Bottom fish	unid. fish	shrimp	mollusk	amphipod	other benth. crust.	mysid	unid. crust	plankt. copepod	harpacticoid copepod	annelid	barnacle cypris larva	other
April	2	D	D	White croaker	9	150	18	67	2												1		
April	2	N	S	White croaker	1	163	19	79	0			3			2						1		
April	2	D	D	White croaker	1	160	19	80	1						2						1		
April	2	D	D	White croaker	6	161	19	94	4												1		
June	2	D	D	White croaker	3	162	19	95	2					2							3		1
April	2	N	D	White croaker	4	166	19	96	5				2								1		
April	2	D	D	White croaker	3	169	20	98	5					2	3						1		
April	2	N	D	White croaker	10	179	21	105	5	1				3	5		4				2		
April	2	N	D	White croaker	8	168	20	108	4						2						1		
April	2	D	D	White croaker	2	175	20	113	2												1		
April	2	D	S	White croaker	1	173	20	115	4				1		3		4				5		2
April	2	D	D	White croaker	5	175	20	116	3			1									2		
April	1	D	D	White croaker	2	181	21	117	4	1		2									3		
April	1	D	D	White croaker	4	185	22	120	3	2					3						1		
April	2	N	D	White croaker	6	180	21	123	4					2							1		
April	1	D	D	White croaker	7	182	21	127	3	2.5				2.5		1					4		
April	2	N	D	White croaker	7	183	21	127	5						2						1		
April	2	D	D	White croaker	4	179	21	128	5			1									2		
April	2	N	D	White croaker	9	182	21	134	5												1		
June	2	D	D	White croaker	1	194	23	163	3					2									1
April	2	N	D	White croaker	2	204	24	176	3												1		
April	1	N	D	White croaker	1	209	24	181	2	1													
April	2	D	D	White croaker	7	193	23	181	5												1		
April	2	N	D	White croaker	3	204	24	186	5								2				1		
April	2	N	D	White croaker	5	208	24	195	5	2			1								3		
April	2	N	D	White croaker	1	206	24	197	5						2						1		
June	1	D	D	White croaker	1	226	26	238	3					2									1
June	2	D	D	White croaker	2	222	26	261	2						2								1