Appendix E

ENTRAINMENT STUDY

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Assessment and Evaluation of Fish and Invertebrate Entrainment Effects from Commercial Aggregate Sand Mining in San Francisco Estuary

February 2009

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Executive Summary

Hanson Aggregate and Jericho/MBT submitted an application to the California State Lands Commission (CSLC) for renewal of twelve commercial sand extraction leases and a private lease within the San Francisco Bay-Delta. Because of concerns about the potential entrainment effect on fish and invertebrate populations in the Estuary that originate from commercial aggregate mining and a lack of applicable scientific studies concerning the subject, Applied Marine Sciences, Inc. (AMS), was requested to conduct a literature-based assessment and evaluation of entrainment by these operations.

Using California Department of Fish and Game (CDFG) data from 2000 to 2007, in conjunction with recent Bay-Delta entrainment studies and studies from the Pacific Northwest, AMS developed estimates associated with expected mining efforts within the three lease areas for various fish, crab, and shrimp taxa. Adult equivalent loss (AEL) methodologies were employed for larval and juvenile taxa where sufficient life history information is known to account for mortality.

In order to evaluate the relative importance of entrainment estimates associated with the proposed mining operations, AMS developed a measure of the population size of individual species of interest within the Estuary employing a methodology used by the CDFG for estimating abundance indices.

Fish Entrainment

Estimates of entrainment were calculated for the eight dominant fish species present in Central Bay, which accounted for 96% of the demersal fish community, as reported by CDFG data. The number of juveniles and adults of a particular species estimated to be entrained by sand mining operations range from 54 to nearly 38,000 individuals per year. Bay gobies were estimated to be the most entrained species (37,901) followed by speckled sanddabs (36,739), plainfin midshipmen (27,393), English sole (22,346), Pacific staghorn sculpin (10,098), and shiner perch (5,802). These entrainment estimates represented between <0.1% and 0.6% of the estimated Central Bay regional abundance index for each species. Based on similar fish entrainment studies from hydraulic dredging activities in the Pacific Northwest, it is known that certain species such as Pacific sand lance, which are present in San Francisco Bay, are typically entrained in large numbers. However, as a result of normal avoidance behaviors, they are typically not reported in demersal fish sampling efforts. Using entrainment data from Grays Harbor, WA, Pacific sand lance could be entrained in numbers as high as 700,000 individuals, if densities are comparable in the two locations.

For the fifteen dominant species inhabiting Suisun Bay and accounting for 97% of the demersal fish community, as reported by CDFG data, individual species entrainment estimates ranged between one and 2,680 individuals occurring per year from sand mining operations in the Middle Ground Shoal lease. Calculated entrainment estimates indicated that Pacific herring (2,680), striped bass (456), Shokihaze goby (268), yellowfin goby (223), Pacific staghorn sculpin (207), starry flounder (103), longfin smelt (73), and plainfin midshipmen (43) are the most entrained fish species.

As observed with the Central Bay entrainment estimates, Pacific herring were primarily entrained by sand mining operations as planktonic larvae. The high entrainment estimates for Pacific herring might be, in part, the result of applying larval entrainment data collected from studies farther west in North and Central Bay, which are closer to known herring spawning grounds. However, if correct, Pacific herring entrainment by sand mining could account for approximately 7.9% of the regional abundance index for Pacific herring in Suisun Bay. Excluding Pacific herring, these levels of entrainment for all other species were estimated to represent between <0.1 % and 0.5% of the total abundance index for each taxa within Suisun Bay.

For the eleven dominant fish species inhabiting the Suisun Marsh sand mining leases, individual entrainment estimates ranged between 0 and 176 individuals occurring per year from sand mining operations in this region of the Estuary. Calculated entrainment estimates indicate that Shokihaze goby (176), yellowfin goby (56), white catfish (45), longfin smelt (21), striped bass (12), channel catfish (7), starry flounder (4), and delta smelt (4) were the most entrained fish species. These levels of entrainment were estimated to represent between <0.1% and 0.2% of the total abundance index for each species within Suisun Marsh. Chinook salmon were estimated to be entrained at a rate of one (1) fish per year as a result of sand mining activities in Suisun marsh. This estimate, however, may be low due to potential underestimates of Chinook salmon presence in CDF&G data from which these entrainment estimates were made.

Crab & Shrimp Entrainment

Of the three Bay mining regions, Central Bay, Suisun Bay (Middle Ground Shoal), and Suisun Marsh, juvenile Dungeness crab are only found in significant numbers in Central Bay and are not regularly observed in Suisun Marsh. In Suisun Bay, between 61 and 79 juvenile crabs were estimated to be entrained by mining operations at Middle Ground Shoal, in years for which crabs are relatively abundant. For years in which the juvenile Dungeness crab population in the Estuary is low, as it has been for the last several years, the estimated annual entrainment of juvenile crabs is less than 1.

Within the Central Bay mining leases, entrainment of Dungeness crab juveniles is predicted to be much higher than that at Middle Ground Shoal. An average of approximately 850 adults were estimated to be removed annually from future populations of adult crabs. Based on the estimated total number of Dungeness crab juveniles inhabiting the Central Bay region of San Francisco Estuary and their estimated survival to adulthood, the juvenile crab entrained by sand mining activities in Central Bay represented approximately 0.2% to 1% of future adult populations over the eight-year study period.

In the Central Bay mining leases, Blacktail shrimp are estimated to be the most frequently entrained species, whereas California Bay shrimp are more heavily entrained in both Middle Ground Shoal and Suisun Marsh. Bay-wide, approximately 1.2 million shrimp are entrained by sand mining activities in the three Bay mining regions, representing an estimated 0.5% of the estimated shrimp abundance indices for those three regions. Of these 1.2 million shrimp, one million are Blacktail shrimp entrained at the Central Bay mining leases.

Special Status Species

To assess the effect of possible entrainment during sand mining on federal or state protected fish species and fish species of special significance to the Estuary, we examined the estimated annual entrainment for six species: Chinook salmon, delta smelt, green sturgeon, longfin smelt, steelhead, and splittail. In the Central Bay mining lease sites, only longfin smelt were predicted to be entrained during sand mining operations. In the Middle Ground Shoal lease area, Chinook salmon, delta smelt, longfin smelt, and splittail were predicted to be entrained. In the Suisun Marsh mining leases, Chinook salmon, delta smelt, longfin smelt, and green sturgeon were predicted to be entrained during sand mining operations. In all three Bay mining lease areas, the percentage of entrained special status fish from sand mining operations is estimated to be less than 0.3% of the regional abundance index for that species of fish. Longfin smelt is the most entrained species with an average of 750, 72, and 20 individuals predicted to be entrained during 2000-2007 in Central Bay, Middle Ground, and Suisun Marsh lease areas, respectively. The other species each have 10 or fewer individuals being entrained per lease area.

Impact on Commercial Fisheries

The potential affect of entrainment from commercial sand mining on commercially important fish and invertebrate taxa in San Francisco Estuary was evaluated for the assessment period of 2000 to 2007. Entrainment of Pacific herring, by sand mining activities, was estimated to have been less than 0.03% of their estimated regional abundance index in all three sand mining regions. This level of entrainment was not expected to result in any meaningful reduction in the Bay herring fishery.

California Bay shrimp is the only commercially important shrimp species harvested within the Estuary. Annual entrainment of California Bay shrimp through sand mining activities was estimated to range between approximately 3% and 6% of annual commercial landings.

Although Dungeness crab is not harvested within San Francisco Estuary, it is an important nursery ground for the species and supplies a significant proportion of harvested adult crab in North Central California coastal waters. In the Central Bay mining leases, entrained juvenile crabs was estimated to account for the loss of between 3 and 1, 536 adults, representing between <0.01% and 0.08%, respectively, of landed Dungeness crab at San Francisco ports, depending on the year. Juvenile crab entrained at Middle Ground Shoal by sand mining operations was estimated to result in the loss of <0.0001% of the landed adult catch between 2000 and 2007. On average, San Francisco Estuary sand mining activities were estimated to cause the loss of < 0.1% of the annual crab harvests through entrainment.

1. Introduction / Overview

Within the San Francisco Bay Estuary (the Estuary), dredging of marine sediments is routinely conducted for the creation and maintenance of harbors, deep water shipping channels, and for commercial aggregate. Dredging for harbors and shipping channels has been conducted in San Francisco since the 1800s, whereas the dredging of sand for commercial construction activities (sand mining) has only been conducted since the 1930s (Hanson, 2004). Sand that has been commercially dredged from Central San Francisco Bay and the western Delta is routinely used for fill material and for making concrete.

Currently, sand mining within the Estuary only occurs within defined lease locations within Central Bay, Middle Ground Shoal, and Suisun Bay channels. Over a twelve-month period beginning in March 2002 and ending in February 2003, 1.6 million cubic yards of material were extracted during 843 mining events at these locations. Although 1.6 million cubic yards of extracted material per year is reported by the mining companies to be representative of annual extraction volumes, state and federal permits allow up to 2.1 million cubic yards of material to be extracted annually (Hanson, 2004; NOAA, 2006). Until just recently, three companies were actively engaged in sand mining activities, Hanson Aggregate Mid-Pacific, Inc. (Hanson Aggregate), RMC/CEMEX, Inc., and Jericho Products, Inc./Morris Tug and Barge (Jericho/MT).

In 2007, leases issued by the California State Lands Commission (CSLC) for the use of State-owned tidal and subtidal lands for commercial sand extraction were about to expire. Hanson Aggregate and Jericho/MT (the applicants) submitted an application to the CSLC for renewal of ten leases in Central Bay, two leases in Suisun Marsh, and a private lease at Middle Ground Shoal, in Suisun Bay. Per the California Environmental Quality Act (CEQA), the CSLC required an environmental assessment of potential effects and impacts of commercial sand mining activities. Because of concerns about the potential effect on fish and invertebrate populations in the Estuary as a result of entrainment associated with commercial aggregate mining and a lack of applicable scientific studies concerning the subject, Applied Marine Sciences, Inc. (AMS) was requested to conduct a literature-based assessment and evaluation of entrainment by these operations.

1.1 Description of Mining Activities

The applicants use an assortment of hydraulic equipment to extract sand from the seafloor of the Estuary (Hanson, 2004). In general, a steel dredge pipe (13-20 inches in diameter), affixed with a 3 x 4 foot drag head, is lowered to the seafloor from a hinged point on the deck of the barge. The dredge pipe is primed with seawater and a sand/water slurry is pumped into a rectangular chute located above the hopper barge and running the length of the barge. Screened gates (3/8”-3/4” in size) are located at even intervals along the bottom of the rectangular chute to size and disperse the material into the hopper barge. Oversized material and debris are pumped to the end of this rectangular chute where it connects to a pipe that directs the material back to the Bay at a location under the barge. Prior to the commencement of actual mining, the hopper barge is filled with water to provide added maneuvering stability, allowing trapped fines to remain suspended and flow overboard through weirs or flashboards located in the walls of the barge. A “potholing” method is the normal operation wherein the barge attempts to remain stationary or move very slowly in a forward direction while extracting sand. A typical mining event load is 1,850 to 2,400 cubic yards of sand, and can take several hours to complete. Operations can be conducted either day or night (Hanson, 2004). During ballasting operations, the drag head is required by State permit to be located no higher off of the seafloor than three feet.

Mining operations can occur in water depths as shallow as 17 feet and as deep as 90 feet, although existing permit conditions only allow it to occur in water depths greater than 30 feet (BCDC, 2008). In the Central Bay leases, mining occurs in an area roughly bounded by Angel Island to the east, the Tiburon peninsula and Richardson Bay to the north, the Golden Gate to the west and the San Francisco Embarcadero to the south (Figure 1-1). In the Delta (Figure 1-2), two State leases and one privately owned lease (Middle Ground Shoal) are located east of Carquinez Strait, and mining in these areas occurs primarily along the upper edge of the shipping channel, along a band of the channel where decreasing water velocity allows the coarser sand fractions to settle out.

1.2 Potential Entrainment and Impingement

Suction head dredging, whether for harbor and channel maintenance (maintenance dredging) or aggregate sand mining, has the capability to affect multiple vertebrate and invertebrate communities inhabiting the Estuary. These include benthic infauna and epifauna, mobile invertebrates such as shrimp and crabs, demersal and pelagic fish, and the planktonic stages of both invertebrates and fish. The suction current created to pump the sand slurry off of the seafloor, up the dredge pipe, and onboard the barge could be too strong for some organisms and age classes to escape being entrained (Hanson, 2004). Precisely what this suction rate is for the assorted taxa and age classes present in the sand mining areas is unknown. The National Marine Fisheries Service (NMFS) has estimated that a water velocity greater than 0.33 fps has the potential to impinge salmon smolts on water diversion screens (NOAA, 2006). It can be assumed that for fish species that are poorer swimmers than salmon, such as longfin smelt, speckled sanddabs, California Bay shrimp, gobies, etc., that suction velocities less than 0.33 fps can be expected to result in entrainment or impingement. For the purposes of this investigation, it is also assumed, as concluded by NOAA in their biological opinion for sand mining (NOAA, 2006) that all fish and macroinvertebrates entrained during sand mining result in 100% mortality.

Based on a careful review of barge vessel operations and observations made during a sand mining event, there are two principal phases of sand mining when entrainment of marine organisms are expected to occur. These include:

- The entrainment of larval invertebrates, larval fish, and adult and juvenile from the seafloor and water column during initial hopper barge ballasting, and
- The entrainment of juvenile and adult fish and invertebrates from the seafloor during sand mining when the drag head is in contact with seafloor sediments.

Benthic infauna inhabiting seafloor sediments are also being removed from the ecosystem along with the mined sand but are not part of this assessment. The effects of sand mining on the benthic infaunal community are addressed in a separate study (AMS, 2009).

Figure 1-1. Commercial Sand Mining Leases in Central Bay Region of San Francisco Bay

Figure 1-2. Commercial Sand Mining Leases in the West Delta Region of San Francisco Bay

2. Methods

2.1 Data Sources

There is a general lack of detailed and pertinent scientific data concerning entrainment of fish and invertebrates from commercial sand mining. There are, however, a few investigations of varying degrees of relevance to this study that have been conducted recently. Typically, larval fish and invertebrate entrainment studies are performed for industrial activities such as power generation and desalination plants that use large volumes of water for cooling or as process feedstock. Under the Clean Water Act, Section 316(b) and environmental regulations governing new development, these operations are required to conduct assessments of the impingement and entrainment of biological species that result from their operations. Two such investigations, an entrainment study conducted for the Mirant Potrero Power Plant, located in Central San Francisco Bay (Tenera, 2005), and the Marin Municipal Water District's (MMWD) pilot desalination project in San Pablo Bay (Tenera, 2007), provide recent information on larval entrainment in the general vicinity of sand mining leases. Pertinent data used from these studies in this assessment are provided in Appendix B.

Similarly, because of all the suction head maintenance dredging that occurs throughout the United States and the potential for significant biological effects, state and federal agencies have conducted assorted studies assessing entrainment from these types of dredging operations in both coastal and inland water locations. Studies conducted in Oregon and Washington (Reine and Clarke (1998), Tegelberg and Arthur (1977); Stevens (1981); Armstrong *et. al.*. (1982, 1987); Dinnel *et. al.*. (1986); McGraw *et. al.*. (1988); Dumbauld *et. al.*. (1988); Larson and Patterson (1989); and Wainwright *et. al.*. (1990, 1992); Pearson et al. (2002, 2003) that investigated fish and Dungeness crab entrainment during channel maintenance operations are also pertinent to this assessment.

Additionally, in 2006 and 2007, two dredging entrainment studies were conducted in San Francisco Bay that have direct relevance to this investigation. They include a study conducted by the sand mining companies in 2006 investigating the potential for entrainment of Chinook salmon by their operations in the San Francisco Delta mining locations (Hanson, 2006), and a study conducted by the National Marine Fisheries Service (NMFS) at the Sonoma Marina in north San Pablo Bay, during harbor deepening (Woodbury, 2008). Data from Hanson and Woodbury reports is provided in Appendix C.

Using the scientific information contained in these studies, in combination with information on site-specific fish and invertebrate population densities, and operational information specific to the proposed sand mining activities, it is possible to calculate entrainment estimates that are indicative of the general magnitude of entrainment that may be occurring, as well as provide benchmarks upon which to assess the potential environmental impact of calculated entrainment estimates.

However, because of the inherent uncertainty present in any fish sampling program regarding representativeness of data collected, the direct applicability of study results that reflect highly site specific environmental and biological community conditions, and the assumptions used to estimate entrainment numbers that must reflect multiple operational, seasonal, and natural life history difference, the entrainment estimates presented in this report should only be considered as “order-of-magnitude” estimates. It is because of this uncertainty in calculated estimates that AMS scientists have employed a preponderance of evidence approach, wherever feasible, to bracket or frame calculated entrainment estimates and the evaluation of the potential environmental impact resulting from sand mining entrainment.

The following sections outline the approaches used to calculate and evaluate fish and invertebrate entrainment occurring as a result of commercial sand mining in the Estuary. The appendices contain the details of our calculations and the enclosed CD includes the Excel spreadsheets used in this assessment.

2.2 Entrainment Estimation Methods

The estimation methods used for different faunal groups were generally similar, but varied to some extent based upon the type of data available and the degree to which age classes were broken out and whether this distinction was important. Estimation methods may also have varied based upon the expected mobility of a particular faunal group, and whether census data available from a single sampling site, or a particular area, were thought to be more representative of the taxa’s presence in a particular region. For each faunal group, however, entrainment estimates are based largely upon species density information in specific lease locations generated through ongoing sampling conducted by the California Department of Fish and Game (CDFG). This information is described briefly below.

CDFG's San Francisco Bay Study and the Interagency Ecological Program for the San Francisco Estuary (IEP) provided data from monthly fish, crab, and shrimp otter trawl and midwater trawl sampling events conducted from 1980 to 2007. Data included information on species type, sampling location, and sampling effort (i.e., trawl duration and area covered), and also broke down data by age class for a limited number of species. For the purposes of this assessment, only data that had completed all CDFG quality assurance requirements were used for analysis. While it was our standard procedure for this investigation to use the most recent eight years of released data (2000-2007), in some cases the most recent data were not available and data from earlier years were used in its place (e.g., 1998-2005 for shrimp). Detailed information on how CDFG conducts their monthly sampling program can be found in (Baxter, *et. al.*, 1999). An image showing the location of all CDFG sampling stations is presented in Figure 2-1. Descriptions of which sampling stations were used in estimates for particular faunal groups and regions are presented below.

There is inherent uncertainty associated with any sampling program. Despite scientific efforts to constantly improve the sampling methodology, there is a large degree of uncertainty with sampling of fish and macroinvertebrate taxa. Captured fish do not represent all taxa that may be present in a sampled location since some species and age classes avoid capture, either through avoidance swimming, behavioral actions such as burrowing into bottom sediments, or are smaller than the net mesh size. As a result, any scientific trawl data must be viewed as an indication of taxa presence and relative species abundances only, and not in terms of absolute numbers.

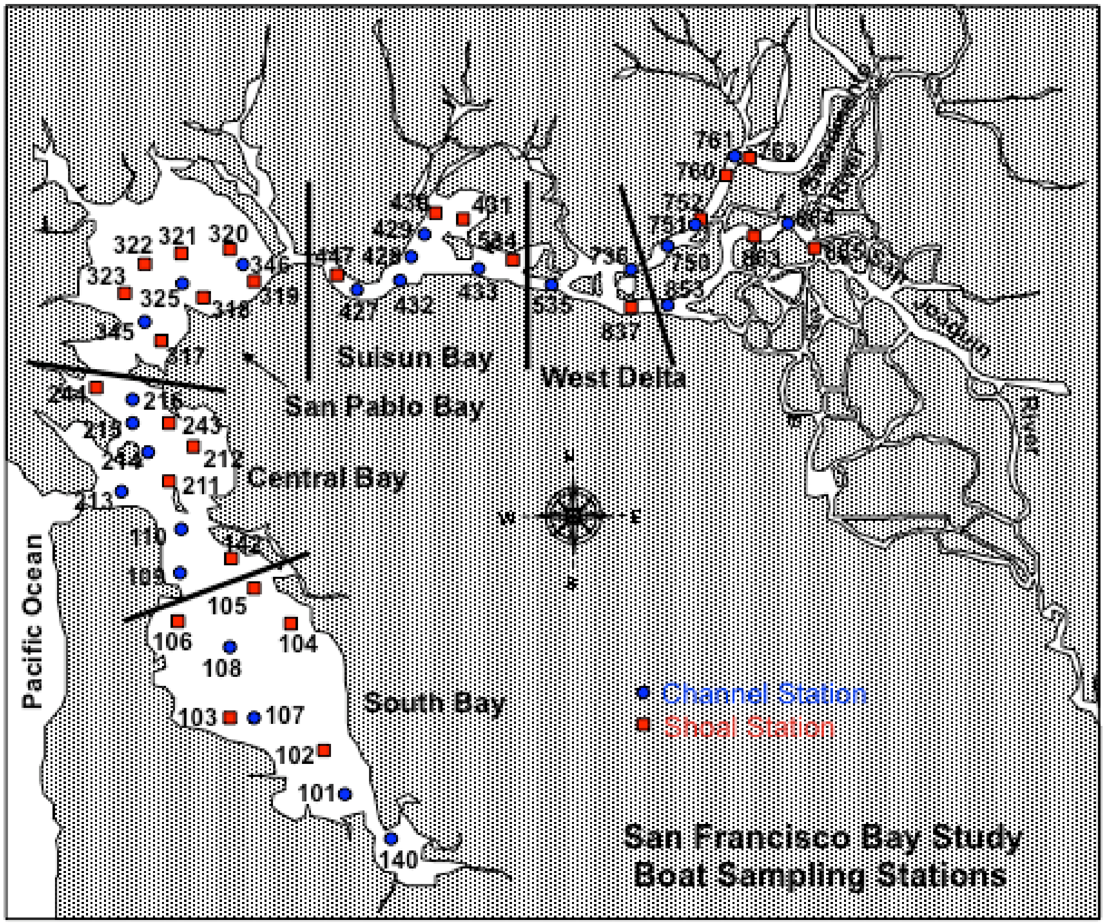

Figure 2-1. Relative Location of CDG Trawling Stations. Graphic courtesy of Kathy Hieb, CDFG

2.2.1 Entrainment Calculations

For each faunal group of interest, entrainment estimates were generated largely in a similar fashion, using estimates of fish density in combination with those of expected mining effort.

For each faunal group, a species density defined as catch per unit effort (CPUE) was calculated for individual fish, shrimp, and crab species data. For calculation of CPUE, CDFG otter trawl data from monthly trawls was initially normalized to trawling effort (i.e., area) associated with that particular trawling event. CPUE for fish, shrimp, and crabs, based upon CDFG otter trawl data for the years 2000 through 2007, was calculated for each month of the year as follows:

$$CPUE_M = (C_{OT} \times 10{,}000) / A_{OT}$$

Where: $CPUE_M$ = Catch per unit effort for month M (fish / ha)

C_{OT} = Number of a particular faunal group collected in an otter trawl sampling event in fish/ha

A_{OT} = Average trawl area (m^2)

10,000 = Conversion factor from hectares (ha) to m^2

This calculation produced an estimate of the number of fish, crabs, or shrimp present per m^2 of seafloor at a CDFG sampling station. One or more CDFG stations were then combined, as described below, to represent potential fish, crab, and shrimp densities present where sand mining occurs.

Mining effort was calculated using reports of previous number of mining events conducted and seafloor area dredged per event. To estimate the number of mining events, information was compiled on the mining events conducted within a one-year period starting in March 2002 and ending February 2003 (Hanson, 2004). The mining companies indicated that the sand mining that occurred within this period is representative of normal annual sand mining activities. This information included the number of mining events per month within each broad lease area and is provided in Appendix A.

The seafloor area dredged per event was calculated from the average length of 39 representative mining events located in all three Bay mining regions (459 m) multiplied by the width of the hydraulic suction drag head plus one quarter of the drag head width on either side (1.38 m). This generated an average area dredged per event of 630 m^2, which was used with each of the various faunal groups to estimate entrainment.

This general methodology was adapted, as required for each faunal group, to better represent real-world conditions, species-specific life histories, and available information. When an adaptation was necessary, the approach is presented below.

2.2.1.1 Fish

Larval, juvenile, or adult fish are entrained during sand mining operations with both the sand and water being pumped to the hopper barge. Larval fish are included in the water being used to initially ballast the barge and to mix with mined sand prior to transport to the hopper barge. Juvenile and adult fish that are incapable of avoiding the suction created by the dredge, and present within close proximity to the drag head during mining, will also be entrained. Estimates of entrainment for all fish taxa that account for at least one percent of the estimated fish present based on CDFG data or that represent a protected species or species of concern were calculated for all three phases of the operations when entrainment is occurring.

Fish Eggs and Larvae

As discussed above, one of the three sources of fish entrainment during sand mining is the anticipated loss of fish larvae contained within the water used to initially ballast the hopper barge and to slurry and move the sand from the seafloor to the hopper dredge. Although it is possible that some of the larvae entrained with this water survive to return to Bay waters, for the purpose of this analysis it was assumed there is 100% mortality. Because the natural mortality rate of larval fish is so high, an adult equivalent loss (AEL) computation approach was used as initially described by Goodyear (1978) and routinely used in power plant and other anthropogenic operations that entrain larval fish (Tenera, 2005; Tenera, 2007).

No known larval fish and fish egg entrainment studies have been conducted in association with hydraulic dredging operations along the west coast of the United States, or more importantly, associated with dredging operations within the Estuary. In order to estimate the magnitude of larval fish and fish egg entrainment by commercial sand mining, two key sets of data are needed: (1) the volume of Bay water used during sand mining operations, and (2) the species composition and density of fish larvae and eggs within the plankton being entrained by the operation along with the water.

Using information contained in Hanson (2004) concerning hopper barge capacities, pump rates, annual volumes of sand mined in each of the three Bay mining regions, and water/sand slurry ratios (Table 2-1), it was possible to calculate the annual volumes of water used to extract the volumes of sand mined in each of the three Bay mining regions, using the following formula:

$$W_R = (WSR_R \times S_R + W_B \times E_R) \times 0.76$$

Where:

- W_R = Total volume of water used for sand mining activities within a Bay mining region (Middle Ground, Suisun Marsh, Central Bay) per year (m^3)
- WSR_R = Water Volume: Sand Volume Ratio used to extract sand within a Bay mining region
- S_R = Representative annual volume of sand extracted within a Bay mining region (yd^3)
- W_B = Maximum volume of ballast water required to fill the hopper barge prior to sand extraction (yd^3)
- E_R = Total number of mining events within a Bay mining region per year
- 0.76 = Conversion factor for converting yd^3 to m^3

There are no current site-specific plankton data available for the three Bay mining regions comparable to the IEP trawling data. Therefore, surrogate data sets were employed as the best available indicator of larval fish and egg species composition and abundance in Bay plankton that can be anticipated to be present in water used in sand mining operations. Entrainment data from the Potrero Power Plant (Tenera, 2005) and the Marin Metropolitan Desalination Pilot Study (Tenera, 2007) were used (Appendix B). These two entrainment study locations are very well-sited to characterize Central Bay plankton entrainment estimates from sand mining activities, where the majority of the sand mining occurs, and to a lesser degree, Delta mining lease locations.

Results from the Potrero and MMWD studies were normalized to water volumes sampled in each investigation to generate a larval entrainment rate (larvae / m^3 water pumped) by species (Table 2-1). The Potrero rates were applied for Central Bay lease areas, and, in the absence of better data, the MMWD rates were used for Middle Ground and Suisun Marsh lease areas. Estimates of total larval and egg entrainment were then generated for sand mining activities by multiplying the calculated entrainment rates for each species in each region by the annual volumes of water used in each Bay mining region (Table 2-1).

Table 2-1. Total Estimated Annual Water Volumes and Operational Data Used in Calculating Annual Water Volumes

	Potrero Power Plant[1]	MMWD[2]	Central Bay Sand Mining Leases[3]	Middle Ground Sand Mining Lease[3]	Suisun Marsh Sand Mining Leases[3]
Max Volume Water: Volume Sand Mined Ratio	-	-	18.34	7.86	10.85
Volume of Sand Mined (yd^3)	-	-	1,291,841	225,793	96,229
# Mining Events (/year)	-	-	630	155	58
Barge Capacity (yd^3)	-	-	2,400	2,400	2,400
Estimated Annual Water Volumes (m^3)	319,399,820	41,450,502	19,272,327	1,640,835	905,139
Ratio of Annual Water Used During Sand Mining to Annual Water Used at Potrero	-	-	0.0603	0.0051	0.0028
Ratio of Annual Water Used During Sand Mining to Annual Water Used at MMWD	-	-	0.4649	0.0396	0.0218

[1] Tenera, 2005; [2] Marin Municipal Water District, Tenera, 2007; [3] Hanson, 2004

These total larvae and egg entrainment estimates were further adjusted to reflect the high natural mortality of larval fish and eggs by estimating how many of the entrained larvae and eggs would have survived to reach adulthood. For example, for the MMWD study, of the 615,864 northern anchovy estimated to be entrained per year, only 45 were calculated to reach adulthood (Tenera, 2007).

One problem with the AEL method of estimating the loss of larvae on future adult fish populations is that detailed age-specific natural survival rates for each species being considered must be available. This information does not exist for the vast majority of fish species inhabiting Estuary waters. For species identified as likely taxa to be entrained by sand mining operations, it exists only for Pacific herring, northern anchovy, and gobies. For these species, the natural mortality of all age classes to adulthood is <0.2% (Table 2-2).

Table 2-2. Estimated Larval Entrainment and Adult Equivalent Loss for Dominant Fish Taxa at the Potrero Power Plant and the Proposed Marin Municipal Water District Desalination Plants

Species	Potrero Power Plant Entrainment Study[1]			MMWD Desalinization Plant Entrainment Study[2]			Average % Survival
	Estimated Total Annual Larval Entrainment	AEL Estimate	% Survival	Estimated Total Annual Larval Entrainment	AEL Estimate	% Survival	
Pacific herring	35,982,833	1,064	0.03%	229,061,594	67,458	0.03%	0.030%
Northern anchovy	49,302,228	11,620	0.16%	615,864	45	0.17%	0.163%
Gobies unident	65,237,852	104,875	0.024%	1,860,969	3,089	0.007%	0.015%

[1] Tenera, 2005; [2] Marin Municipal Water District, Tenera, 2007; [3] Hanson, 2004

We used known cumulative larval survival rates from Estuary fish taxa as surrogates for those species present, but for which detailed age-class natural mortality rates are unknown, to calculate AEL estimates for the entrainment impact of plankton loss. Although this approach introduces a small degree of uncertainty, it allows us to estimate fish loss due to larval and egg entrainment. This approach was believed to be better than ignoring the potential effect on important fish taxa for which age-specific mortality data are not available.

These AEL estimates previously developed for Pacific herring, Northern anchovy, and gobies were used directly for these three species. They were also applied to other fish species for which no known AEL have been previously developed as shown in Table 2-3. These assignments were based on taxonomic or habitat similarities between the species.

Table 2-3 Average Adult Survival Percentages Used to Calculate Adult Equivalent Loss (AEL) Estimates

Surrogate Fish Taxa	Average % Survival to Adulthood	Fish Taxa to Which Surrogate % Survival to Adulthood Applied
Pacific herring	0.030	Pacific herring, delta smelt, longfin smelt, smelts unident
Northern anchovy	0.163	Northern anchovy
Gobies unident	0.015	Yellowfin goby, Shokihaze goby, bay goby, gobies unident., speckled sanddab, Pacific sanddab, English sole, Pacific staghorn sculpin, starry flounder

Adult and Juvenile Fish Entrainment

To account for potential foraging and other normal movements of fish within the general area of a mining lease and areas immediately adjacent to a mining lease area, data from demersal trawls collected at multiple sites within a particular region of the Estuary were compiled to use in estimating individual taxa densities for the entrainment calculations. For the Central Bay mining lease areas, data from CDFG sampling stations 213, 214, and 215 were used (Figure 2-1). For Middle Ground, data from CDFG sampling stations 428, 432, and 534, were used, and for Suisun Marsh, data from CDFG sampling stations 433, 535, and 736 were similarly used. To then generate total entrainment estimates of juvenile and adult fish associated with sand mining operations, we estimated the entrainment associated with the two distinct phases of the sand mining operation: (1) entrainment during sand extraction and (2) entrainment during ballasting.

Entrainment, Sand Extraction Phase

To estimate entrainment associated with the sand extraction phase we used the otter trawl fish densities (i.e., CPUE) calculated for each mining lease area (Central Bay, Suisun Bay (Middle Ground), and Suisun Marsh), an estimate of the average area of seafloor over which a typical mining event occurs, and the number of mining events, per month, in that region over a typical year according to the following formula:

$$F_s = \left(\frac{1}{N_{OT}}\right) \times \sum_{i=1}^{12} (CPUE_{OT_i} \times N_i \times A_D) / 10{,}000$$

Where:

F_S	=	Total fish estimated to be entrained in month M through sand extraction
N_{OT}	=	Number of CDFG otter trawl stations for which CPUE data were calculated (i.e., 3 per mining area)
$CPUE_{OT}$	=	Catch per unit effort estimate from CDFG otter trawls (fish /m^2) for month M
N_i	=	Number of estimated dredging events in month i
A_D	=	Surface area transited in average mining event (630 m^2)
10,000	=	Conversion factor from hectares to m^2

Entrainment, Ballasting Phase

To estimate the entrainment of juvenile and adult fish during initial barge ballasting, when it occurs, fish entrainment information from the Hanson (2006) Chinook salmon entrainment study was used. The key to entrainment of juvenile and adult fish during this phase of each sand mining event is the suction rate at which water is being pulled into the drag head when it is placed approximately 3 feet off the seafloor, and whether that suction rate is sufficient to entrain individuals that are present. Since the Hanson (2006) entrainment study was entirely conducted with the drag head/suction pipe head of all three mining barges in this position, the data from the study are particularly relevant.

Using the fish entrainment data from Hanson (2006), an entrainment rate for each of the four fish species entrained in Middle Ground (n=24 samples) and at Suisun Marsh (n=33 samples) was calculated. Data from the Benicia/Carquinez test site (Appendix C) was not used because of uncertainty regarding the pump operations and dredging equipment differences during sampling and the applicability of the Benicia/Carquinez lease area, which is no longer within the proposed mining lease. The number of each species entrained was normalized to volume of water sampled to develop the number of fish entrained per cubic meter of water pumped, according to the following formula:

$$R_B = \sum_{i=1}^{N} \frac{F_i}{V_i}$$

Where:
- R_B = Rate of entrainment of a particular species of fish (fish/m^3) during all sampling events
- F_i = Number of fish of a species entrained in sampling event i
- V_i = Volume of water pumped during sampling event i

It should be noted that the entrainment study by Hanson (2006) was conducted during a period associated with relatively low densities and resultant low abundance indices for many fish species (Appendices E and F). For obvious reasons, we did not apply the above-calculated rate of entrainment directly to other species, mining areas, and time frames, as it reflects more the site-specific conditions present at time of sampling. Instead, we assumed that this entrainment rate calculated for the ballasting phase is proportional to the entrainment rate of fish associated with the sand extraction phase (i.e., that ballasting operations would be entraining fish from the same basic population of demersal fish as sand extraction, and would therefore fluctuate with densities of these demersal fish as do the estimates for entrainment associated with sand extraction).

Therefore, in order to apply the above-calculated entrainment rates to other species, mining areas, and time periods, calculated entrainment rates associated with ballasting phase (R_B values) were normalized to reflect the number of fish present in the mining lease site at the time the tests were conducted.   To accomplish this, it was necessary to execute two additional calculations. The first was used to estimate the number of fish entrained through ballasting operations in Middle Ground and Suisun Marsh mining areas using Hanson (2006) entrainment rates:

$$F_B = R_B \times V_B \times N$$

Where:
- F_B = Total number of fish of a particular species that would be entrained during ballasting operations (fish/month)
- R_B = Rate of entrainment of a particular species of fish (fish/m^3) calculated from Hanson (2006) in the above equation
- V_B = Max volume of ballasting water pumped during a mining event (m^3/event)[1]
- N = Typical number of mining events per month

[1] As a conservative estimate, we used the worst-case scenario of a 2400 yd^3 (1835 m^3) capacity barge being filled completely with water before initiating sand extraction.

The second calculation was used to relate entrainment observed through Hanson (2006) sampling (F_B) to estimated entrainment for other species, mining areas, and time periods (F_{BX}):

$$F_{BX} / F_{SX} = F_B / F_S$$

Where: F_{BX} = Total number of fish of a particular species within a specific Bay mining region estimated to be entrained during ballasting operations during a specific time period

F_{SX} = Total number of fish of a particular species within a specific Bay mining region estimated to be entrained during sand extraction operations during that time period

F_B = Total number fish of a particular species that would be entrained during ballasting operations as estimated from Hanson (2006) entrainment rates and typical mining effort

F_S = Total number fish of a particular species estimated to be entrained through sand extraction operations within the corresponding Bay mining region and time period of Hanson (2006) sampling

Of the four species entrained by Hanson (2006) the two with the highest entrainment rate were used as a conservative approach to estimating juvenile and adult fish entrainment during water ballasting operations, which were splittail and striped bass (Table 2-4).

We next calculated the ratio of entrainment through ballasting to entrainment through sand extraction for splittail and striped bass. For this effort, entrainment was recalculated over a representative time period that would encompass the Hanson (2006) sampling effort, May through July for Middle Ground sampling activities and April through July for Suisun Marsh sampling. The resulting ratio of entrainment through ballasting to that of extraction (F_B / F_S) for splittail within Middle Ground and striped bass within Suisun Marsh were both calculated as 0.2 (Table 2-4). Although there were only two species to choose from, we feel this is a conservative estimate owing to the fact that for the overwhelming majority of fish species resident within Middle Ground and Suisun Marsh mining regions, there was no entrainment by Hanson (2006).

Substituting the 0.2 ratio of fish entrained via ballasting to fish entrained via sand extraction (F_B / F_S) calculated for our two species of interest, the previous formula for calculation of entrainment through water ballasting reduces to:

$$F_{BX} = 0.2 \text{ x } F_{SX}$$

Where: F_{BX} = Number of fish entrained via water ballasting phase for a particular species, mining area, and time period

F_{SX} = Number of fish entrained via sand extraction phase for the same species, mining area, and time period

Table 2-4. Calculation of Ratio of Fish Entrained through Ballasting Operations to Fish Entrained via Sand Mining, for Middle Ground and Suisun Marsh

	Splittail	Striped Bass
Region	Middle Ground	Suisun Marsh
# Fish Entrained (Hanson, 2006)	1	1
Avg Entrainment Rate (fish/m^3) (Hanson, 2006)	0.00005	0.00002
# Fish Entrained Per Mining Event (fish/event) (rate x 1835 m^3)	0.08	0.04
Avg # of Monthly Mining Events Associated with Hanson (2006) Sampling	16	7
# Fish Entrained Per Month	1.4	0.3
Est. Entrainment During Ballasting Operations During June 2006	7.8	1.3
Ratio Entr. During Ballasting Phase to that Entr. During Sand Extraction	0.2	0.2

Entrainment, Combined Ballasting and Sand Extraction Phases

Total adult and juvenile fish entrained via ballasting and sand extraction phases was then calculated as shown in the following formula:

$$F_T = F_B + F_S$$

Where:
F_T = Total fish of a particular species estimated to be entrained in a particular Bay mining area
F_B = Fish entrained during ballasting
F_S = Fish entrained during sand extraction

2.2.1.2 Crab

We employed two different techniques for estimating entrainment of crabs through sand mining operations. The first method is generally similar to those developed and described above for fish, relying upon estimates of crab density combined with anticipated mining effort. A second method references the results of previous entrainment investigations conducted associated with sand mining operations outside of the Bay Area. Each is described in more detail below.

Primary Entrainment Estimating Method

Crab distribution within the Estuary was assumed to be highly variable based on site-specific ecological conditions. As a consequence, it was decided that otter trawl data from the CDFG sampling station closest in proximity to the mining leases, and that was similar in water depth and location to the channel for the Delta mining sites, would be the most representative of what taxa and at what abundances would be present during mining activities. The CDFG sampling sites used for each region were 213 for Central Bay, 433 for Middle Ground, and 535 for Suisun Marsh.

The main focus of the analysis of crab data was the only commercially important species present in San Francisco Bay, Dungeness crab (*Cancer magister*). Otter trawl data provided by CDFG segregated crabs collected into two age classes, age 0 and age 1+, based upon size at the time of collection. For the purposes of analysis of CDFG data, all *C. magister* were assigned a birth month of January because this is when peak hatching occurs in the Gulf of the Farallones, even though age 0 crabs typically do not enter the Estuary until April or May (Hieb, 1999). The size demarcation used to delineate between the two classes is represented in Table 2-5.

Table 2-5. Maximum Carapace Size Applied to Age 0 Dungeness Crab Used by CDFG in Differentiating Age 0 and Age 1 Juveniles (From Hieb (1999))

Month	Carapace size (mm)
April	20
May	35
June	55
July	70
August	80
September	90
October	105
November	115
December	125

Entrainment was then calculated for the two different age classes using the following formula:

$$C_E = (CPUE \times N_M \times A_D) / 10,000$$

Where:

C_E	=	Total crabs in a particular age class estimated to be entrained per region per month
CPUE	=	Catch per unit effort estimate from CDFG otter trawls (crabs/ha)
N_M	=	Number of estimated dredging events in a particular region in month M
A_D	=	Surface area transited in average mining event (m^2)
10,000	=	Conversion factor from hectares to m^2

Entrainment estimates from the two different age classes were then summed to generate an overall entrainment estimate of the total number of crabs entrained per month. The monthly estimates were then summed to generate an annual estimate of juvenile crab entrainment.

As a large proportion of crabs likely to be entrained through proposed dredging operations would not have reached adulthood as a result of natural mortality, we next generated an estimate of the adult equivalent loss (AEL) that the above entrainment estimates represented. Estimates of AEL were prepared by multiplying the total number of crabs within an age class by the natural survivorship of that age class to achieve adulthood. Data from Wainwright (1992) were used for this calculation and are presented in Table 2-6 below.

Table 2-6. Percentage of Juvenile *C. magister* Surviving from Each Season Until a 2+ Age Class (Adapted from Wainwright, 1992)

Season	Age Class 0+ (%)	Age Class 1+ (%)
Winter (Jan, Feb, March)	6.35	38.00
Spring (April, May)	0.87	10.70
Summer (June, July, August, Sept)	0.17	16.00
Fall (Oct, Nov, Dec)	3.40	25.50

Alternative Entrainment Estimation Methods

For purposes of comparison, an alternate method of estimating crab entrainment was employed following the Dredging Impact Model (DIM) developed by Wainwright *et. al.,* (1992) and McGraw *et. al.,* (1988) in Grays Harbor, Washington. Wainwright and McGraw used data collected over several years of channel maintenance dredging by the Army Corps of Engineers on the main channel into Grays Harbor to develop a formula that facilitated the estimation of the number of crabs that would be expected to be entrained by hopper suction dredge activities within the harbor. This formula is based on otter trawl estimates of local juvenile Dungeness crab densities and the volume of material to be dredged. The final formula is:

$$C_E = 0.27 \times CPUE \times V_Q$$

Where:
- C_E = Total juvenile crabs in any particular age class estimated to be entrained per region per calendar quarter per 1000 yd^3 of material dredged
- CPUE = Catch per unit effort (crabs/ha) for local Dungeness crab densities
- V_Q = Volume of material dredged per calendar quarter Q (yd^3) (Appendix A)

The relationship of juvenile crab density to actual entrained crabs is reflected by a slope-of-entrainment calculated to be 0.27, which was developed from multiple years of paired trawling and entertainment measurements. This factor is specific to Grays Harbor and may not accurately reflect the same relationship in the San Francisco Estuary or any other estuary along the Pacific coast. Comparable work done along the Columbia River Estuary navigation channel by Pacific International Engineering (2002) and Pearson *et. al.,* (2002, 2003) indicated that the slope-of-entrainment calculated for the Columbia River was different than that developed by Wainwright for Grays Harbor. Depending on where along the Columbia River navigation channel you compared crab densities and actual crab entrainment rates they would vary, resulting in different slopes-of–entrainment. It was because of the apparent site-specificity of the DIM estimating method that this analysis employed a different primary approach to calculating Dungeness crab.

However, because of its past broad use in estimating crab entrainment rates, it was decided that using this alternative entrainment estimating method would be appropriate as a way of providing a comparison number for annual sand mining crab entrainment in the Estuary. As with the juvenile entrainment estimates calculated above, adult equivalent loss (AEL) estimates were calculated following the same methodologies as presented above and as described by Wainwright *et. al.,* (1992) and Hanson (2004).

2.2.1.3 Shrimp

Similar to the situation for crabs, shrimp are also thought to be relatively immobile species compared with fish. Therefore, data from otter trawls collected at a single CDFG sampling site thought to be most representative of the region under consideration were used to estimate entrainment at each of the three regions. Like crabs, the CDFG sampling sites used for each region were 213 for Central Bay, 433 for Middle Ground, and 535 for Suisun Marsh.

Seven different species of shrimp were reported collected in CDFG otter trawls for the study period 1998 to 2005. These include California Bay shrimp (*Crangon franciscorum*), Blacktail bay shrimp (*Crangon nigricauda*), Blackspotted bay shrimp (*Crangon nigromaculata*), Siberian prawn (*Exopalaemon modestus*), Stimpson coastal shrimp, (*Heptacarpus stimpsoni*), Smooth bay shrimp (*Lissocrangon stylirostris*), and Oriental shrimp (*Palaemon macrodactylus*).

Entrainment estimates were calculated for each shrimp species of interest using the following formula.

$$S_E = (CPUE \times N_M \times A_D) / 10{,}000$$

Where:

S_E	=	Number of a particular shrimp species estimated to be entrained per region in a particular month
CPUE	=	Catch per unit effort estimate from CDFG trawls (shrimp/ha)
N_M	=	Number of estimated dredging events in month M
A_D	=	Surface area transited in average mining event (m^2)
10,000	=	Conversion factor from hectares to m^2

Annual entrainment associated with a particular lease location(s) was then estimated as the sum of the monthly entrainment estimates. An annual entrainment was estimated for each of the seven shrimp species reported by CDFG.

2.2.2 Population Estimates

In order to evaluate the relative importance of fish and macroinvertebrate entrainment estimates associated with the proposed mining operations, it was necessary to have some measure of the "population" abundance of individual species of interest within the Estuary. Similar to the method employed by CDFG for estimating abundance indices for monitored taxa within the Estuary[2], we next calculated abundance indices for all CDFG reported species for each of the three Bay regions in which sand mining occurs, Central Bay, Suisun Bay (Middle Ground) and Suisun Marsh.

In generating these abundance indices, it is obvious that use of only otter trawl data would ignore fish present in the Estuary that preside predominantly in the upper regions of the water column but who also frequent the demersal zone. We therefore developed a two-box model in which pelagic fish are represented by the upper box and demersal fish through the lower box, and fish

[2] Abundance indices are used as measures of the population of the species in question, and used mainly by CDFG as a trend analysis tool to measure growth or decline of different species over time.

within both of these boxes are estimated through CDFG trawling efforts to develop regional abundance indices for each represented taxa. For the lower box, fish densities are estimated from CPUE values calculated from otter trawl efforts as discussed previously. For the upper box, fish densities are similarly estimated from CPUE values, generated from midwater trawl efforts in this case, which are thought to be more representative of the upper reaches of the water column. Fish density (CPUE) for midwater trawl data was calculated in a similar fashion to that of otter trawls, with the only difference being in how effort was reported for the trawls (i.e., as a regional volume (m^3) rather than area (m^2)):

$$CPUE_M = (C_{MWT} \times 10{,}000) / V_{MWT}$$

Where:
- $CPUE_M$ = Catch per unit effort associated with upper box (fish/ha-m)
- C_{MWT} = Number of a particular faunal group collected in a MWT sampling event
- 10,000 = Conversion factor from hectare-meters (ha-m) to cubic meters (m^3)
- V_{MWT} = Trawl volume (m^3)

For the purposes of this investigation, an annual abundance index for each species by region was then calculated as follows:

$$AI = (CPUE_{OT} \times RWF_{OT}) + (CPUE_{MWT} \times RWF_{MWT})$$

Where:
- AI = Abundance index of a particular taxa in a particular region
- $CPUE_{OT}$ = Catch per unit effort estimate from otter trawls collected in a particular region in a particular year (species/ha)
- RWF_{OT} = Area regional weighting factor calculated by CDFG
- $CPUE_{MWT}$ = Catch per unit effort estimate from midwater trawls collected in a particular region in a particular year (species/ha-m)
- RWF_{MWT} = Volume regional weighting factor calculated by CDFG

It should be noted that abundance indices for this assessment were calculated in a slightly different manner than those used by CDFG. CDFG calculates their indices using CPUE averaged from only the months where species are found to be most numerous in trawls. For this assessment, we used data from all months since dredging operations may occur over the full course of the year and entrainment and abundance were calculated on a monthly basis.

The CDFG regional weighting factors represent the area or volume within a particular Bay region greater than 3 ft in depth relative to mean lower low water (MLLW) (Kathy Hieb, 2009; personal communication). Regional weighting factors for each of the five CDFG-defined regions are shown in Table 2-7, although only data from regions 2, 4, and 5 were used for this assessment.

Table 2-7. CDFG Regional Weighting Factors for San Francisco Bay

Region #	Region	Area (m^2)	Volume (m^3)
1	South Bay	250,150,000	1,505,380,000
2*	Central Bay	216,340,000	2,865,130,000
3	San Pablo Bay	153,540,000	861,400,000
4*	Suisun Bay	55,290,000	471,640,000
5*	West Delta	28,010,000	253,680,000

* Data used from this region to calculate annual abundance indices

There are two main areas of uncertainty in using the CDFG trawl data and calculated abundance indices in place of population estimates: (1) the sampling does not follow a randomized design, and (2) the collection efficiency of an individual trawl relative to what would be entrained via dredging operations is unknown. However, lacking better data or estimates of abundance for target species for the time period during which these calculations are being estimated, it was determined that using the CDFG data to calculate abundance indices was the best available approach and that comparisons of entrained fish or macroinvertebrates to these abundance indices would provide a meaningful approximation of the severity of the potential impact.

To incorporate the best possible geographical representation, all CDFG sampling stations within a region were averaged to estimate a regional CPUE for each species of interest by trawl type. This incorporates eleven stations associated with the Central Bay region, nine within the Suisun Bay region associated with Middle Ground leases, and three within the West Delta region associated with Suisun Marsh leases.

As mentioned previously, there are certain inherent problems with using trawl data alone as the basis upon which to estimate a population abundance of an individual fish or macroinvertebrate taxon. For example, for shrimp and very small juvenile and adult fish, otter trawl data probably under-samples and thereby underestimates their abundances. Smaller individuals may slip through the larger mesh openings of the trawl or slip under the trawl as it moves along the bottom. The otter trawl can be expected to effectively sample those larger fish taxa that are not fast swimmers and who swim up off the bottom when startled, such as most flatfish. Alternatively, for crabs, the otter trawl was likely to be more efficient for smaller size individuals than for larger ones that may be mobile enough to escape the net opening. Fish species like Pacific sand lance, which burrow into the seafloor when startled, as an escape behavior, will most likely be absent from the demersal trawl data or reported in numbers much lower than their actual presence. Alternatively, these fish will represent a highly entrained species because they cannot escape the suction dredge (McGraw and Armstrong, 1990).

Therefore, it is assumed that captured taxa and the numbers of individuals per taxa caught are indicators of what species may be present in a location or region of the Estuary, but do not represent absolute numbers. As long as these inherent data limitations are considered when conducting the evaluation and in formulating conclusions, they are still useable as the best data available.

3. Results

Estimates of fish and key macroinvertebrate entrainment were made on a monthly or quarterly basis, depending on the faunal group, and then summed to provide annual entrainment numbers. This allowed for the review of important fish species that are not year-round residents of a specific Bay mining region, but become numerically dominant or important during certain times of the year, such as Chinook salmon, longfin smelt, delta smelt, etc.

3.1 Fish

Fish entrainment calculations were developed for the two broad categories of larval fish, and adult and juvenile fish. For each category, fish that represent at least one percent of calculated abundance index are represented within the entrainment calculations.

3.1.1 Fish Larvae

Table 3.1 lists the estimated larval fish and egg entrainment in Central Bay, Suisun Marsh, and Middle Ground sand mining regions. AEL estimates associated with this entrainment are provided in Tables 3-3, 3-5, and 3-7 along with juvenile and adult entrainment estimates.

3.1.2 Adult and Juvenile Fish

In the Central Bay lease area, nine species of fish were identified as individually comprising at least one percent of the total abundance, and collectively accounting for ninety-six percent of all fish taxa present over the 2000-2007 analysis period (Table 3-2). Seventy-seven additional fish taxa were identified as being present in either the midwater or otter trawls but were only occasionally present and collectively accounted for less than four percent of the total abundance of fish within the region (Appendix D). Table 3-3 presents the total annual entrainment estimates for Central Bay mining leases for the nine dominant fish taxa identified for the region. Appendix D contains tables presenting the monthly and annual estimates of entrainment for each of these taxa for the study period 2000 through 2007.

In the Middle Ground lease area, fourteen species of fish were identified as individually comprising at least one percent of the total abundance of all fish within the Middle Ground Shoal region, and collectively accounting for ninety-seven percent of all fish taxa present during the 2000-2007 study period (Table 3-4). An additional thirty-three fish were collected in either midwater or otter trawls and were each estimated to individually comprise less than three percent of the total abundance of fish within the region (Appendix E). Table 3-5 presents the total annual entrainment estimates for Middle Ground mining leases for the fourteen dominant fish taxa identified for the region. Appendix F contains tables presenting the monthly and annual estimates of entrainment for each of these taxa for the assessment period 2000 through 2007.

In the Suisun Marsh lease area, eleven species of fish were identified as individually comprising at least one percent of the total abundance of all fish, and collectively accounted for ninety-seven percent of all fish taxa present during the 2000-2007 study period (Table 3-6). An additional thirty-three fish taxa were collected in midwater or otter trawls and were individually estimated to compose less than three percent of the total abundance of fish within the region (Appendix F). Table 3-7 presents the total annual entrainment estimates for Suisun Marsh mining leases for the eleven dominant fish taxa identified for the region. Appendix F contains tables presenting the

Table 3-1. Estimated Larval Fish Entrainment at Central Bay, Middle Ground and Suisun Marsh Mining Lease Areas Based on Recent Regional Larval Entrainment Studies

Taxon		Estimated Larval Entrainment Based on the Potrero Power Plant 316(b) Entrainment Study (Tenera, 2005)			Estimated Larval Entrainment Based on the MMWD Proposed Desalination Plant Study (Tenera, 2007)		
Common Name	**Species**	**Central Bay**	**Middle Ground**	**Suisun Marsh**	**Central Bay**	**Middle Ground**	**Suisun Marsh**
Bay goby	*Lepidogobius lepidus*	6,294,141	535,880	295,609	14,627	1,245	687
Gobies	Gobiidae unid.	3,936,399	20,222	184,876	865,254	73,667	40,637
Northern anchovy	*Engraulis mordax*	2,974,857	15,283	139,716	286,345	24,379	13,448
Pacific herring	*Clupea pallasii*	2,171,175	11,154	101,971	106,501,724	9,067,497	5,001,931
Yellowfin goby	*Acanthogobius.flavimanus*	1,763,757	9,061	82,836	263,098	22,400	12,357
White croaker	*Genyonemus lineatus*	379,023	1,947	17,801	7,251	-	-
California halibut	*Paralichthys californicus*	96,205	494	4,518	-	-	-
Pacific staghorn sculpin	*Leptocottus armatus*	56,329	289	2,646	29,834	2,540	1,401
Speckled sanddab	*Citharichthys stigmaeus*	39,633	204	1,861	-	-	-
Herrings and anchovies	Clupeiformes	28,171	145	1,323	-	-	-
Larval fishes, damaged	larval fish - damaged	21,586	111	1,014	355,282	30,249	16,686
Pacific sand lance	*Ammodytes hexapterus*	19,062	98	895	-	-	-
Rockfishes	*Sebastes* spp.	19,064	98	895	3,820	325	179
Sand sole	*Psettichthys melanostictus*	16,874	87	793	-	-	-
Starry flounder	*Platichthys stellatus*	-	-	-	3,874	330	182
Flounders	Pleuronectidae unid.	14,659	75	688	-	-	-
Diamond turbot	*Hypsopsetta guttulata*	11,836	61	556	10,868	925	510
Larval fishes	larval/post-larval fish, unid.	11,521	59	541	10,987	935	516
Croakers	Sciaenidae unid.	8,107	42	381	-	-	-
Pipefishes	*Syngnathus* spp.	7,288	37	342	-	-	-
Jacksmelt	*Atherinopsis californiensis*	5,873	30	276	-	-	-
Monkeyface eel	*Cebidichthys violaceus*	4,428	23	208	3,838	327	180
Silversides	Atherinidae unid.	3,780	19	178	3,507	299	165
Sculpins	*Oligocottus* spp.	3,727	19	175	-	-	-
Prickle backs	Stichaeidae unid.	3,659	19	172	-	-	-
Bay pipefish	*Syngnathus leptorhynchus*	2,751	14	129	-	-	-
Smelts	Osmeridae unid.	2,335	12	110	49,567	4,220	2,328

Taxon		Estimated Larval Entrainment Based on the Potrero Power Plant 316(b) Entrainment Study (Tenera, 2005)			Estimated Larval Entrainment Based on the MMWD Proposed Desalination Plant Study (Tenera, 2007)		
Common Name	**Species**	**Central Bay**	**Middle Ground**	**Suisun Marsh**	**Central Bay**	**Middle Ground**	**Suisun Marsh**
Pacific sanddab	*Citharichthys sordidus*	2,200	11	103	-	-	-
Sculpins	Cottidae unid.	2,096	11	98	-	-	-
Prickly sculpin	*Cottus asper*	-	-	-	39,370	3,352	1,849
Blackeye goby	*Coryphopterus nicholsi*	2,048	11	96	-	-	-
Northern lampfish	*Stenobrachius leucopsarus*	1,894	10	89	-	-	-
English sole	*Parophrys vetulus*	1,875	10	88	-	-	-
Cabezon	*Scorpaenichthys marmoratus*	1,369	7	64	-	-	-
Snailfishes	Cyclopteridae unid.	1,277	7	60	-	-	-
Queenfish	*Seriphus politus*	1,133	6	53	-	-	-
Rock sole	*Pleuronectes bilineatus*	1,053	5	49	-	-	-
Sculpins	*Clinocottus* spp.	1,031	5	48	10,427	888	490
Topsmelt	*Atherinops affinis*	1,001	5	47	-	-	-
Longjaw mudsucker	*Gillichthys mirabilis*	949	5	45	-	-	-
Clinid kelpfishes	*Gibbonsia* spp.	947	5	44	-	-	-
Blennies	*Hypsoblennius* spp.	924	5	43	-	-	-
Flatfishes	Pleuronectiformes unid.	809	4	38	-	-	-
Clingfishes	*Gobiesox* spp.	372	2	17	-	-	-
Lefteye flounders & sanddabs	Paralichthyidae unid.	346	2	16	-	-	-
Giant kelpfish	*Heterostichus rostratus*	324	2	15	-	-	-
Greenlings	Hexagrammidae unid.	324	2	15	-	-	-
Lingcod	*Ophiodon elongatus*	315	2	15	-	-	-
Sculpins	*Artedius* spp.	289	1	14	-	-	-
Butter sole	*Pleuronectes isolepis*	271	1	13	-	-	-
Snailfishes	*Liparis* spp.	254	1	12	-	-	-
Gunnels	Pholididae unid.	242	1	11	-	-	-
Codfishes	Gadidae	237	1	11	-	-	-
Brown Irish lord	*Hemilepidotus spinosus*	211	1	10	-	-	-
Sanddabs	*Citharichthys* spp.	207	1	10	-	-	-
Total Fish Larvae		**17,920,241**	**595,606**	**841,637**	**108,459,673**	**9,232,643**	**5,093,031**

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Table 3-2. Estimated Abundance of Fish Representing at Least 1% of Total Fish Present in the Central Bay Sand Mining Lease Area (CDFG, 2000-2007)

Common Name	Scientific Name	Demersal Abundance	Pelagic Abundance	Total Abundance	% Total
Northern Anchovy	*Engraulis mordax*	0	156,342,341	156,342,341	75.8%
Pacific Herring	*Clupea pallasii*	114,919	9,872,726	9,987,645	4.8%
Speckled Sanddab	*Citharichthys stigmaeus*	9,379,637	4,320	9,383,958	4.5%
Bay Goby	*Lepidogobius lepidus*	7,663,975	12,460	7,676,435	3.7%
Plainfin Midshipman	*Porichthys notatus*	5,749,682	33,600	5,783,282	2.8%
English Sole	*Parophrys vetulus*	4,757,233	3,057	4,760,291	2.3%
Pacific Sardine	*Sardinops sagax*	10,202	2,736,584	2,746,786	1.3%
Shiner Perch	*Cymatogaster aggregata*	1,595,338	649,176	2,244,513	1.1%
Pacific Staghorn Sculpin	*Leptocottus armatus*	1,822,135	3,696	1,825,832	0.9%

Table 3-3. Estimated Average Annual Entrainment for Species Representing at Least 1% of Central Bay Abundance Indices

Common Name	Scientific Name	Estimated Entrainment During Sand Extraction	Estimated Entrainment During Ballasting	Estimated Larval Entrainment, (AEL)	Estimated Total Annual Entrainment	Estimated Annual Abundance Index (AI)	Percentage of Avg. AI Entrained
Northern Anchovy	*Engraulis mordax*	0	0	459	459	156,342,341	0.0%
Pacific Herring	*Clupea pallasii*	345	69	641	1,055	9,987,645	0.0%
Speckled Sanddab	*Citharichthys stigmaeus*	30,562	6,112	65	36,739	9,383,958	0.4%
Bay Goby	*Lepidogobius lepidus*	23,015	4,603	10,810	37,901	7,676,435	0.5%
Plainfin Midshipman	*Porichthys notatus*	22,828	4,566	0	27,393	5,783,282	0.5%
English Sole	*Parophrys vetulus*	18,619	3,724	3	22,346	4,760,291	0.5%
Pacific Sardine	*Sardinops sagax*	45	9	ND	54	2,746,786	0.0%
Shiner Perch	*Cymatogaster aggregata*	4,835	967	ND	5,802	2,244,513	0.3%
Pacific Staghorn Sculpin	*Leptocottus armatus*	8,415	1,683	92	10,098	1,825,832	0.6%

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Table 3-4. Estimated Abundance of Fish Representing at Least 1% of Total Fish Present in Middle Ground Sand Mining Lease Area (CDFG, 2000-2007)

Common Name	Scientific Name	Demersal Abundance	Pelagic Abundance	Total Abundance	% Total
Striped Bass	*Morone saxatilis*	191,625	153,318	344,943	20.8%
Northern Anchovy	*Engraulis mordax*	0	312,724	312,724	18.9%
Longfin Smelt	*Spirinchus thaleichthys*	52,152	193,489	245,641	14.8%
Yellowfin Goby	*Acanthogobius flavimanus*	135,088	16,728	151,817	9.2%
Shokihaze Goby	*Tridentiger barbatus*	122,743	2,344	125,086	7.5%
American Shad	*Alosa sapidissima*	4,393	108,782	113,174	6.8%
Pacific Staghorn Sculpin	*Leptocottus armatus*	80,031	3,221	83,251	5.0%
Starry Flounder	*Platichthys stellatus*	50,965	3,246	54,211	3.3%
Chinook Salmon	*Oncorhynchus tshawytscha*	444	44,410	44,854	2.7%
Plainfin Midshipman	*Porichthys notatus*	26,386	7,900	34,286	2.1%
Pacific Herring	*Clupea pallasii*	1,365	32,650	34,015	2.1%
Threadfin Shad	*Dorosoma petenense*	1,668	20,826	22,494	1.4%
Delta Smelt	*Hypomesus transpacificus*	2,302	17,939	20,242	1.2%
Splittail	*Pogonichthys macrolepidotus*	3,699	14,537	18,235	1.1%

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Table 3-5. Estimated Average Annual Entrainment for Species Representing at Least 1% of Middle Ground Abundance Indices

Common Name	Scientific Name	Estimated Entrainment During Sand Extraction	Estimated Entrainment During Ballasting	Estimated Larval Entrainment, (AEL)	Estimated Total Annual Entrainment	Estimated Annual Abundance Index (AI)	Percentage of Avg. AI Entrained
Striped Bass	*Morone saxatilis*	380	76	0	456	344,943	0.1%
Northern Anchovy	*Engraulis mordax*	0	0	4	4	0	NA
Longfin Smelt	*Spirinchus thaleichthys*	60	12	1	73	245,641	0.0%
Yellowfin Goby	*Acanthogobius flavimanus*	155	31	37	223	151,817	0.1%
Shokihaze Goby	*Tridentiger barbatus*	223	45	-	268	125,086	0.2%
American Shad	*Alosa sapidissima*	20	4	0	23	113,174	0.0%
Pacific Staghorn Sculpin	*Leptocottus armatus*	169	34	4	207	83,251	0.2%
Starry Flounder	*Platichthys stellatus*	85	17	1	103	54,211	0.2%
Chinook Salmon	*Oncorhynchus tshawytscha*	1	0	0	1	44,854	0.0%
Plainfin Midshipman	*Porichthys notatus*	36	7	-	43	7,900	0.5%
Pacific Herring[1]	*Clupea pallasii*	2	0	2678	2,680	34,015	7.9%
Threadfin Shad	*Dorosoma petenense*	2	0	0	3	22,494	0.0%
Delta Smelt	*Hypomesus transpacificus*	5	1	1	7	20,242	0.0%
Splittail	*Pogonichthys macrolepidotus*	8	2	0	10	18,235	0.1%

[1] Larval entrainment estimate for Pacific herring is thought to be a gross overestimate, due to translating results generated for a high-density area in San Pablo Bay to that of a low-density area in Suisun Bay.

Table 3-6. Estimated Abundance of Fish Representing at Least 1% of Total Fish Present in the Suisun Marsh San Mining Lease Area (CDFG, 2000-2007)

Common Name	Scientific Name	Demersal Abundance	Pelagic Abundance	Total Abundance	% Total
American Shad	*Alosa sapidissima*	4,323	171,029	175,352	24.4%
Striped Bass	*Morone saxatilis*	78,212	50,684	128,896	18.0%
Threadfin Shad	*Dorosoma petenense*	235	94,068	94,304	13.1%
Shokihaze Goby	*Tridentiger barbatus*	70,957	0	70,957	9.9%
Longfin Smelt	*Spirinchus thaleichthys*	12,351	46,066	58,417	8.1%
Yellowfin Goby	*Acanthogobius flavimanus*	26,133	19,994	46,127	6.4%
Delta Smelt	*Hypomesus transpacificus*	2,368	31,159	33,527	4.7%
White Catfish	*Ameiurus catus*	25,582	2,045	27,627	3.8%
Chinook Salmon	*Oncorhynchus tshawytscha*	332	22,194	22,526	3.1%
Channel Catfish	*Ictalurus punctatus*	19,717	0	19,717	2.7%
Starry Flounder	*Platichthys stellatus*	7,318	1,719	9,037	1.3%

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Table 3-7. Estimated Average Annual Entrainment for Species Representing at Least 1% of Suisun Marsh Abundance Indices

Common Name	Scientific Name	Estimated Entrainment During Sand Extraction	Estimated Entrainment During Ballasting	Estimated Larval Entrainment, (AEL)	Estimated Total Annual Entrainment	Estimated Annual Abundance Index (AI)	Percentage of Avg. AI Entrained
American Shad	*Alosa sapidissima*	0	0	0	0	175,352	0.0%
Striped Bass	*Morone saxatilis*	10	2	0	12	128,896	0.0%
Threadfin Shad	*Dorosoma petenense*	0	0	0	0	98,276	0.0%
Shokihaze Goby	*Tridentiger barbatus*	91	18	66	176	70,957	0.2%
Longfin Smelt	*Spirinchus thaleichthys*	17	3	1	21	58,417	0.0%
Yellowfin Goby	*Acanthogobius flavimanus*	30	6	20	56	46,127	0.1%
Delta Smelt	*Hypomesus transpacificus*	3	1	1	4	33,527	0.0%
White Catfish	*Ameiurus catus*	38	8	-	45	27,627	0.2%
Chinook Salmon	*Oncorhynchus tshawytscha*	0	0	0	1	22,526	0.0%
Channel Catfish	*Ictalurus punctatus*	6	1	-	7	19,717	0.0%
Starry Flounder	*Platichthys stellatus*	3	1	0.3	4	9,037	0.0%

monthly and annual estimates of entrainment for each of these taxa for the assessment period 2000 through 2007.

3.2 Crab

As conducted for all dominant fish species shown above, estimates of entrainment of Dungeness crab (*Cancer magister*) by mining region were also calculated. Estimates of entrainment were prepared for each month and year for the assessment period of 2000-2007. Initial crab entrainment estimates were prepared using two different juvenile age classes (Age 0 and Age 1+) in order to calculate the potential effect on the adult population. A similar approach to calculating AEL for fish was used to calculate that of crabs. Tables 3-8 and 3-9 show estimated crab entrainment in the Central Bay lease sites. Tables 3-10 and 3-11 show estimated crab entrainment the Middle Ground mining lease. *C. magister* is not reported to inhabit the waters of Suisun Marsh (CDFG, 2000-2007) and was not represented within CDFG trawls, so no entrainment calculations were made for that region.

Table 3-8. Quarterly Entrainment Estimates for Age 0 and Age 1+ Juvenile Dungeness Crab in the Central Bay Mining Leases

	Winter		Spring		Summer		Fall		Annual Total	
	0	1+	0	1+	0	1+	0	1+	0	1+
2000	0	785	61	776	16,153	125	8,707	272	24,921	1,958
2001	0	560	0	3,953	40,471	1,444	256	64	40,727	6,021
2002	0	1,605	351	2,712	19,589	636	4,988	0	24,928	4,953
2003	0	2,320	14,578	952	9,605	382	1,227	0	25,410	3,655
2004	0	572	60,137	6,320	15,515	1,091	8,475	0	84,127	7,982
2005	0	1,558	193	253	649	255	0	0	842	2,066
2006	0	0	0	0	55	0	34	0	90	0
2007	0	0	0	0	4,529	0	1,148	0	5,677	0
Avg.	***0***	***925***	***9,415***	***1,871***	***13,321***	***492***	***3,105***	***42***	***25,840***	***3,330***

Table 3-9. Quarterly AEL Entrainment Estimates for Age 0 and Age 1+ Juvenile Dungeness Crab in the Central Bay Mining Leases

	Winter		Spring		Summer		Fall		Annual Total		Abundance Index AEL		% Regional AEL	
	0	1+	0	1+	0	1+	0	1+	0	1+	0	1+	0	1+
2000	0	298	1	83	27	20	296	69	323	471	27,133	51,702	1.2%	0.9%
2001	0	213	0	423	67	231	9	16	75	883	12,180	161,331	0.6%	0.5%
2002	0	610	3	290	32	102	170	0	205	1,002	16,527	157,167	1.2%	0.6%
2003	0	882	127	102	16	61	42	0	184	1,045	30,606	116,390	0.6%	0.9%
2004	0	217	523	676	26	175	288	0	837	1,068	47,961	218,322	1.7%	0.5%
2005	0	592	2	27	1	41	0	0	3	660	230	135,648	1.2%	0.5%
2006	0	0	0	0	0	0	1	0	1	0	125	614	1.0%	0.0%
2007	0	0	0	0	7	0	39	0	47	0	4,920	1,595	0.9%	0.0%
Avg.	***0***	***352***	***82***	***200***	***22***	***79***	***106***	***11***	***209***	***641***	***17,460***	***105,346***	***1.1%***	***0.5%***

Table 3-10. Quarterly Entrainment Estimates for Dungeness Crab for All Age Classes at Middle Ground Mining Lease (Age 0[1])

	Winter	Spring	Summer	Fall	Annual Total
2000	0	0	0	0	0
2001	0	0	68	0	68
2002	0	0	54	25	79
2003	0	0	27	34	61
2004	0	0	0	0	0
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
Avg.	***0***	***0***	***19***	***7***	***26***

[1] Only Age 0 juvenile crabs were reported in demersal trawl data used to calculate entrainment estimates.

Table 3-11. Quarterly Entrainment AEL Estimates for Dungeness Crab for All Age Classes in Middle Ground Shoal (Age 0[1])

	Winter	Spring	Summer	Fall	Annual Total	Abundance Index AEL	% of AI AEL Entrainment
2000	0	0	0	0	0	42,271	0.000%
2001	0	0	0	0	0	135,255	0.000%
2002	0	0	0	1	1	113,467	0.001%
2003	0	0	0	1	1	100,268	0.001%
2004	0	0	0	0	0	60,197	0.000%
2005	0	0	0	0	0	1,775	0.000%
2006	0	0	0	0	0	0	NA
2007	0	0	0	0	0	13,355	0.000%
Avg.	***0***	***0***	***0***	***0***	***0***	***58,323***	***0.000%***

[1] Only Age 0 juvenile crabs were reported in demersal trawl data used to calculate entrainment estimates.

3.3 Shrimp

Approximately seventeen (17) species of caridean shrimp are reported to currently inhabit the San Francisco Estuary (Baxter *et. al.*, 1999). Of these species, six dominate overall shrimp abundances. These include the California Bay shrimp (*Crangon franciscorum*), Blacktail shrimp *(C. nigricauda)*, Blackspotted shrimp *(C. nigromaculata)*, Stimpson coastal shrimp *(Heptacarpus stimpsoni)*, Smooth bay shrimp *(Lissocrangon stylirostris*), and Oriental shrimp (*Palaemon macrodactylus*). The latter is a non-native species introduced in the 1950s, which has become one of the most abundant shrimp species in the Estuary (Baxter *et. al*., 1999).

Of the six dominant shrimp species in the Estuary, only *C. franciscorum* is deliberately harvested commercially. The other species are occasionally included in commercial trawl catch and, along with *C. franciscorum,* represent an important food prey item for many fish species that inhabit the Estuary and a key component of the food web (Baxter *et. al.*, 1999). Estimates of entrainment were calculated for each of these dominant shrimp species that were present in the three Bay mining regions, based on CDFG monthly sampling data. Tables 3-12 through 3-16 present annual entrainment estimates for the Central Bay lease areas, Tables 3-17 through 3-21 show estimates for Middle Ground lease areas, and Tables 3-22 through 3-24 show estimates for Suisun Marsh mining lease areas.

Table 3-12. Entrainment Estimates of California Bay Shrimp (*C. franciscorum*) in Central Bay Mining Leases

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	887	2885	5841	829	1002	13952	28159	14076	82342	44588	11487	3848	209,895	101,762,024	0.2%
1999	255	2934	73584	163	5953	6604	2152	1191	716	1626			95,177	20,967,602	0.5%
2000	4559	5869	214	1143	425	1696	9241	3294	4170	4772	29	3480	38,891	10,964,146	0.4%
2001	255	204		5538	1640	2450	7480	2630	268	3690	1321	10377	35,854	15,783,039	0.2%
2002		5265	321	508	0	2114	4262	2558	920	1875	1688	3715	23,227	7,940,532	0.3%
2003	2089	1640	1166	2744	0	1153	3052	470	3355	676	1292	775	18,411	7,286,919	0.3%
2004	285	322	240	1463	7654	16247	1036	8116	781	520	517	974	38,156	20,940,716	0.2%
2005	1567	89	1662	0	740	649	1387	3235	2237	1209	2986	855	16,616	27,903,348	0.1%
Avg.	***1414***	***2401***	***11861***	***1548***	***2177***	***5608***	***7096***	***4446***	***11849***	***7369***	***2760***	***3432***	***59,529***	***26,693,541***	***0.3%***

Table 3-13. Entrainment Estimates of Blacktail shrimp (*C. nigricauda)* in Central Bay Mining Leases

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	2349	2773	7978	2515	11815	81405	11987	11567	100347	27007	3274	5273	268,290	72,404,277	0.4%
1999	34593	16210	80707	4671	6439	9905	41088	17820	1118	1414			213,965	103,501,463	0.2%
2000	8609	17606	9923	15926	307440	103126	103236	20546	4377	40877	29	5149	636,842	121,014,204	0.5%
2001	1554	511		33202	323440	667626	49080	23225	54747	113682	3733	51482	1,322,282	197,694,102	0.7%
2002		44777	96141	104661	680855	546947	169426	47460	7707	15235	12612	7793	1,733,614	277,217,965	0.6%
2003	55430	26032	41031	339844	598075	347835	264659	67983	183844	30058	27566	2538	1,984,895	235,575,125	0.8%
2004	11758	2254	988	16003	417681	463839	41402	99863	61386	22497	804	6696	1,145,171	140,407,562	0.8%
2005	14609	179	8216	10932	20260	93253	136416	283826	86419	100991	71157	36188	862,446	225,513,278	0.4%
Avg.	***18414***	***13793***	***34998***	***65969***	***295751***	***289242***	***102162***	***71536***	***62493***	***43970***	***17025***	***16446***	***1,020,938***	***171,665,997***	***0.6%***

Table 3-14. Entrainment Estimates of Blackspotted Shrimp (*C. nigromaculata)* in Central Bay Mining Leases

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	48	22	0	0	213	115	381	0	293	2198	459	143	3,871	35,720,040	0.01%
1999	306	107	1068	0	547	367	0	1941	0	71			4,407	37,907,113	0.01%
2000	306	215	61	610	0	610	4246	78	83	795	0	142	7,146	16,916,800	0.04%
2001	0	51		0	0	4948	564	64	0	0	0	0	5,627	14,063,004	0.04%
2002		102	0	254	0	0	0	44	0	134	0	164	699	14,183,424	0.00%
2003	0	0	155	0	0	384	0	118	447	119	86	0	1,310	16,636,378	0.01%
2004	102	72	0	0	820	0	148	941	49	116	0	214	2,461	19,717,423	0.01%
2005	878	30	237	42	0	216	0	1235	895	0	1149	0	4,681	53,322,147	0.01%
Avg.	***234***	***75***	***217***	***113***	***197***	***830***	***667***	***553***	***221***	***429***	***242***	***95***	***3,775***	***26,058,291***	***0.02%***

Table 3-15. Entrainment Estimates of Stimpson Coastal Shrimp (*Heptacarpus stimpsoni)* in Central Bay Mining Leases

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	24	67	0	0	0	0	0	39	1122	983	517	570	3,323	5,820,018	0.1%
1999	1223	930	1425	33	2369	262	717	44	0	0			7,003	24,730,717	0.0%
2000	229	429	61	76	2855	916	1249	78	124	2068	345	326	8,756	34,871,647	0.0%
2001	0	102		127	5715	6149	1691	321	1387	6362	0	4821	26,674	76,829,682	0.0%
2002		2709	18245	10161	50923	10041	1598	3308	77	636	1964	559	100,221	55,816,520	0.2%
2003	36019	984	3264	48063	15158	1922	6715	706	3355	1431	948	160	118,725	53,091,980	0.2%
2004	408	36	214	213	4647	3669	814	941	342	578	57	47	11,966	21,756,857	0.1%
2005	0	0	47	83	289	432	7659	28524	537	9129	6088	997	53,786	19,092,211	0.3%
Avg.	***5415***	***657***	***3322***	***7345***	***10245***	***2924***	***2555***	***4245***	***868***	***2648***	***1417***	***1069***	***41,307***	***36,501,204***	***0.1%***

Table 3-16. Entrainment Estimates of Smooth Bay Shrimp (*Lissocrangon stylirostris*) in Central Bay Mining Leases

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	0	0	0	0	0	807	0	510	8417	35798	14473	8265	68,270	3,201,850	2.1%
1999	9986	3364	3205	784	2187	2201	0	309	403	2686	-	-	25,124	11,874,933	0.2%
2000	1707	787	550	152	0	0	10407	7685	3881	3976	0	997	30,143	1,397,229	2.2%
2001	0	0	-	203	0	0	564	1027	2505	7379	8902	5224	25,804	1,384,493	1.9%
2002	-	1533	0	0	0	0	133	88	1342	234	1206	2926	7,464	469,936	1.6%
2003	3006	1610	1710	0	1690	0	0	118	1342	3101	5944	1362	19,882	1,067,596	1.9%
2004	1467	36	0	0	0	0	148	176	49	58	574	1900	4,408	264,471	1.7%
2005	878	0	47	0	0	0	0	0	447	445	4020	1995	7,833	421,744	1.9%
Avg.	***2435***	***916***	***787***	***142***	***485***	***376***	***1406***	***1239***	***2298***	***6710***	***5017***	***3239***	***23,616***	***2,510,281***	***1.7%***

Table 3-17. Entrainment Estimates of California Bay Shrimp (*C. franciscorum) in* Middle Ground Shoal Mining Lease

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	0	0	0	0	0	0	0	14075	7615	8053	1416	370	31,529	80,804,251	0.0%
1999	0	0	0	0	10246	4089	8091	2129	10879	7247	-	-	42,680	48,581,099	0.1%
2000	0	0	0	139	3524	7105	8558	7019	28003	11360	1743	583	68,033	44,711,733	0.2%
2001	0	802	-	348	224	13046	13997	10583	11265	2774	3854	343	57,236	40,847,295	0.1%
2002	-	168	0	4383	5093	7731	13861	7917	5745	6487	1884	351	53,621	45,330,094	0.1%
2003	0	0	0	14	46	10320	12299	6361	3210	9088	3187	426	44,952	29,608,220	0.2%
2004	0	437	0	97	224	2969	12061	11239	12914	3181	2280	689	46,091	28,162,997	0.2%
2005	0	260	0	0	381	0	17892	1983	12246	9578	1740	828	44,907	20,434,202	0.2%
Avg.	***0***	***208***	***0***	***623***	***2467***	***5657***	***10845***	***7663***	***11485***	***7221***	***2301***	***513***	***48,631***	***42,309,986***	***0.1%***

Table 3-18. Entrainment Estimates of Blacktail shrimp (*C. nigricauda)* in Middle Ground Shoal Mining Lease

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	158,040	0.000%
1999	0	0	0	0	0	0	0	0	0	0			0	9,766	0.000%
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	1,315,987	0.000%
2001	0	0		13	0	0	0	0	0	9	0	0	21	2,760,502	0.001%
2002	-	0	0	0	0	0	0	0	0	0	27	0	27	2,428,603	0.001%
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	1,199,839	0.000%
2004	0	0	0	0	0	0	33	0	0	0	0	0	33	1,398,440	0.002%
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	401,116	0.000%
Avg.	***0***	***0***	***0***	***2***	***0***	***0***	***4***	***0***	***0***	***1***	***4***	***0***	***10***	***1,209,037***	***0.001%***

Table 3-19. Entrainment Estimates of Blackspotted Shrimp (*C. nigromaculata)* in Middle Ground Shoal Mining Lease

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
1999	0	0	0	0	0	0	0	0	0	0	-	-	0	0	-
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	538	0.000%
2001	0	0	-	0	0	0	0	0	0	0	0	0	0	1,037	0.000%
2002	-	0	0	0	0	0	0	0	0	0	0	0	0	2,904	0.000%
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	3,590	0.000%
Avg.	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***1,009***	***0.000%***

Table 3-20. Entrainment Estimates of Stimpson Coastal Shrimp (*H. stimpsoni)* in Middle Ground Shoal Mining Lease

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
1999	0	0	0	0	0	0	0	0	0	0	-	-	0	0	-
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
2001	0	0	-	0	0	0	0	0	0	0	0	0	0	0	-
2002	-	0	0	0	0	0	0	0	0	0	0	0	0	3,498	0.000%
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Avg.	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***437***	***0.000%***

Table 3-21. Entrainment Estimates of Oriental Shrimp (*P. macrodactylus)* in Middle Ground Shoal Mining Lease

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	8	0	0	0	0	0	0	3	0	0	46	0	58	70,461	0.1%
1999	0	0	0	0	0	0	17	12	8	21	-		58	22,242	0.3%
2000	0	0	0	0	0	0	17	60	19	31	7	0	133	118,621	0.1%
2001	0	0	-	37	37	73	99	0	433	292	106	0	1,077	724,370	0.1%
2002	-	4	0	184	22	129	41	73	2	20	4	0	479	130,010	0.4%
2003	0	0	0	60	0	0	79	6	34	5	11	0	194	62,875	0.3%
2004	0	0	0	0	0	108	112	29	7	14	14	0	283	114,120	0.2%
2005	0	2	0	0	4	0	14	0	106	40	4	0	170	74,292	0.2%
Avg.	***1***	***1***	***0***	***35***	***8***	***39***	***47***	***23***	***76***	***53***	***27***	***0***	***306***	***164,624***	***0.2%***

Table 3-22. Entrainment Estimates of California Bay Shrimp (*C. franciscorum*) in Suisun Marsh Mining Leases

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	65	0	0	0	0	0	0	0	0	0	239	0	304	638,021	0.0%
1999	0	0	0	0	1014	0	17	3205	2335	4478	-	-	11,048	4,639,594	0.2%
2000	932	0	0	0	0	32	3275	2286	2481	1457	199	0	10,662	6,435,343	0.2%
2001	1644	93	-	596	470	4676	919	27	2726	676	268	0	12,095	4,880,816	0.2%
2002	-	32	0	2542	1865	1491	1450	3040	2264	1406	71	0	14,160	7,642,189	0.2%
2003	0	0	0	45	0	646	1403	1009	983	851	228	0	5,165	2,480,411	0.2%
2004	0	97	0	239	842	11373	7505	2094	1352	712	433	0	24,648	8,158,091	0.3%
2005	30	0	0	0	0	0	2187	141	7962	5053	489	0	15,861	6,406,906	0.2%
Avg.	***382***	***28***	***0***	***428***	***524***	***2277***	***2094***	***1475***	***2513***	***1829***	***275***	***0***	***11,743***	***5,160,171***	***0.2%***

Table 3-23. Entrainment Estimates of Blackspotted Shrimp (*C. nigromaculata)* in Suisun Marsh Mining Leases

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
1999	0	0	0	0	0	0	0	0	0	0	-	-	0	0	-
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
2001	0	0	-	0	0	0	0	0	0	0	0	0	0	1,674	0.000%
2002	-	0	0	0	0	0	0	0	0	0	0	0	0	0	-
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Avg.	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.000%***

Table 3-24. Entrainment Estimates of Oriental Shrimp (*P. macrodactylus)* in Suisun Marsh Mining Leases

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	Abundance Index (AI)	Proportion of AI Entrained Annually
1998	0	5	5	0	0	0	0	938	124	100	383	4	1,561	1,331,656	0.1%
1999	0	0	0	0	0	0	10	0	306	55	-	-	371	596,339	0.1%
2000	0	0	0	15	8	22	28	159	181	750	56	6	1,225	538,852	0.2%
2001	0	0	-	133	363	1566	2222	1417	535	247	963	14	7,461	1,819,119	0.4%
2002	-	36	46	339	596	278	1428	468	97	375	54	10	3,728	2,635,660	0.1%
2003	0	0	12	181	34	118	1511	239	253	34	0	28	2,410	945,255	0.3%
2004	0	0	0	14	224	186	861	212	36	21	26	29	1,608	355,746	0.5%
2005	0	7	0	0	58	0	249	117	50	194	62	9	746	957,940	0.1%
Avg.	***0***	***6***	***9***	***85***	***160***	***271***	***789***	***444***	***198***	***222***	***221***	***14***	***2,389***	***1,147,571***	***0.2%***

4. Discussion

Hydraulic suction head dredging creates an environmental condition where benthic infauna and epifauna, adult and juvenile fish, mobile macroinvertebrates, and planktonic larvae are captured (entrained) along with the sand and water (Hanson, 2004; LFR, 2004). Scientific concerns about the potential ecological effect of fish and invertebrate taxa entrainment by suction dredges have resulted in numerous studies being conducted since the late 1970s (Reine and Clarke, 1998 in their review of Tegelberg and Arthur, 1977; Stevens, 1981; Armstrong *et. al.*., 1982, 1987; Dinnel *et. al.*., 1986; McGraw *et. al.*., 1988; Dumbauld *et. al.*., 1988; Larson and Patterson, 1989; and Wainwright, *et. al.*., 1990, 1992). The majority of these investigations were primarily concerned with hydraulic suction dredge entrainment of Dungeness Crab and salmon by maintenance dredging operations in Grays Harbor, WA and Puget Sound, Oregon and Washington. Other more recent or pertinent studies concerning entrainment by hydraulic dredging equipment include Nightingale and Simenstad (2001), Pacific International Engineering (2002), Pearson and Williams (2002), Woodbury (2008), AHI (1992), and Hanson (2006). These latter three studies were conducted in San Francisco Bay, with the AHI and Hanson studies specifically targeting sand mining operations.

What these studies collectively reveal is that benthic infauna is particularly vulnerable to entrainment, with mobile megabenthic and demersal organisms slightly less so (Nightingale and Simenstad, 2001). In addition the physical environmental conditions present at the dredging location, local population dynamics (species presence, density, seasonal movements), and the natural behavior patterns of individual species effect what taxa are entrained as well as the total number of individuals per species susceptible to entrainment. Because most of these studies were conducted to assess the potential environmental effect of maintenance dredging for regulatory and resource managers, study results are typically presented as the number of entrained individuals, for a specific taxa, per volume of material dredged. Data reported in this manner cannot, unfortunately, be readily applied to other locations because of critical differences between the sites in terms of the physical conditions and biological community parameters mentioned above.

Woodbury (2008) demonstrated that small fish (both adults and juveniles) are capable of being entrained during routine harbor maintenance operations in San Pablo Bay and in numbers greater than previously assumed. Hanson (2006) demonstrated that even when the drag head is approximately three feet off the seafloor, as it is during barge ballasting operations, and when operating at normal or near normal operational pump speeds, small adult and juvenile fish are entrained. Hanson (2006) also demonstrated that when fish are potentially concentrated in a shallow channel, some sand mining equipment can create sufficient suction to capture larger and faster swimming species, including Chinook salmon smolts. One final observation from the Hanson (2006) study is that entrainment of fish during the night may be greater than during daylight hours.

In our evaluation of the potential ecological effects of sand mining entrainment in the San Francisco Estuary, results from these studies will be presented where appropriate and meaningful.

4.1 Fish Entrainment

4.1.1 Juvenile and Adult Fish Entrainment

Because of important differences in the fish and macroinvertebrate populations, as well as the amount of sand mining that occurs within each Bay mining region, the discussion of potential ecological effects of sand mining entrainment will be presented relative to the three different Bay mining areas.

4.1.1.1 Central Bay

Entrainment estimates were calculated for the eight species that dominate the demersal fish population determined to be present in the Central Bay mining leases based on CDFG sample data. The number of juveniles and adults of a particular species entrained by sand mining operations ranged from 54 to 37,901 individuals per year (Table 3-3). Bay gobies are estimated to be the most entrained species (37,901) followed by speckled sanddabs (36,739), plainfin midshipmen (27,393), English sole (22,346), Pacific staghorn sculpin (10,098), and shiner perch (5,802). These entrainment estimates represented between <0.1% and 0.6% of the estimated Central Bay regional abundance index for each species. All of the Northern anchovy and most of the Pacific herring are predicted to be entrained as planktonic larvae. Bay gobies were also entrained in significant numbers as planktonic larvae.

It should be noted that in the Potrero Power Plant 316(b) entrainment study (TENERA, 2005), Pacific sand lance *(Ammodytes hexapterus)* was one of the dominant taxa accounting for 11% of all larvae collected, yet no sand lance are reported by CDFG in their monthly sampling program. This lack of reporting by CDFG is not unusual, given the natural behavior of the sand lance, which is to burrow into the seafloor when startled or avoiding a predator. This behavior results in their avoiding capture by bottom trawls but also results in significant entrainment by suction dredges (McGraw & Armstrong, 1990). McGraw & Armstrong reported that Pacific sand lance were the most entrained fish during channel dredging in Grays Harbor, WA, yet were not observed in any of the side-by-side trawls conducted as part of the study. They estimated that Pacific sand lance were being entrained at a rate of 594 individuals per 1,000 cubic yards of dredged material. Based on their larval presence in Central Bay plankton, their known presence in the Estuary, and documented entrainment by suction dredges, it should be assumed that Pacific sand lance are also being entrained in significant numbers in San Francisco Bay as a result of aggregate sand mining operations. If their density in Central San Francisco Bay is similar to Grays Harbor, Pacific sand lance could be directly entrained as adults and juveniles in numbers as high as 700,000 individuals per year, which would make them also the most entrained fish species in San Francisco Central Bay by an order magnitude over all other estimated taxa.

4.1.1.2 Suisun Bay (Middle Ground Shoal)

Estimates of entrainment were calculated for the fifteen dominant species identified from monthly trawl data to best represent the demersal fish community inhabiting Middle Ground Shoal (Table 3-6). Individual species entrainment estimates ranged between one and 2,680 individuals occurring per year from sand mining operations. Calculated entrainment estimates indicate that Pacific herring (2,680), striped bass (456), Shokihaze goby (268), yellowfin goby (223), Pacific staghorn sculpin (207), starry flounder (103), longfin smelt (73), and plainfin midshipmen (43) were the most entrained fish species.

As observed with the Central Bay entrainment estimates, Pacific herring were primarily entrained by sand mining operations as planktonic larvae. The high entrainment estimates for Pacific herring might be, in part, the result of applying larval entrainment data collected from studies farther west in North and Central Bay, which are closer to known herring spawning grounds. However, if correct, Pacific herring entrainment by sand mining could account for approximately 7.9% of the regional abundance index for Pacific herring in Suisun Bay. Excluding Pacific herring, these levels of entrainment for all other species were estimated to represent between <0.1 % and 0.5% of the total abundance index for each within Suisun Bay.

It should also be noted that longfin smelt, delta smelt, and Chinook salmon were also estimated to be entrained by Middle Ground mining operations, with 73, 7, and 1 fish being entrained annually, respectively. The low estimate for Chinook salmon could, in part, be the result of this species being under-represented in CDFG otter trawl data. Chinook salmon's natural ability to avoid the slow moving trawl, their behavioral tendency to inhabit demersal waters only during nighttime hours and to inhabit pelagic waters during daylight hours, and the collection of CDFG trawls predominantly during daylight hours, all contribute to very low reported densities for Chinook salmon in the data used to estimate fish entrainment. Additional discussion on entrainment of species of special significance is presented below.

4.1.1.3 Suisun Marsh

Estimates of entrainment were calculated for the eleven dominant species identified from CDFG monthly trawl data to best represent the demersal fish community inhabiting the Suisun Marsh sand mining leases (Table 3-8). Individual species entrainment estimates ranged between 0 and 176 individuals occurring per year from sand mining operations. Calculated entrainment estimates indicate that Shokihaze goby (176), yellowfin goby (56), white catfish (45), longfin smelt (21), striped bass (12), channel catfish (7), starry flounder (4), and delta smelt (4) were the most entrained fish species. These levels of entrainment were estimated to represent between 0% and 0.2% of the total abundance index for each species within Suisun Marsh. Chinook salmon were estimated to be entrained at a rate of one (1) fish per year as a result of sand mining activities in Suisun marsh. As discussed previously for the Suisun Bay mining operations, this estimate may be low due to potential underestimates of Chinook salmon presence in CDFG data from which these entrainment estimates were made.

McGraw & Armstrong (1990) and Larson & Moehl (1990) as summarized by Reine and Clarke (1998) in their study on the potential entrainment effects from suction dredging in Grays Harbor, WA, calculated potential entrainment rates per 1000 cubic meters of dredged sand for the dominant species entrained in their study (Table 4-1). Along with McGraw and Armstrong's (1990) and Larson & Moehl's (1990) estimates, we calculated comparable ratios for Woodbury (2008) data from Sonoma Marina in San Pablo Bay, as well as for the estimated entrainment rates per species calculated in this study for San Francisco Estuary sand mining operations. These calculations are based on mining volumes for the "representative" March 2002 to

February 2003 year in Central Bay and the Delta mining leases. Assuming similar fish densities between the four locations in this comparison suggests that for most species in San Francisco Estuary, estimated annual entrainment rates (fish/cubic yard of dredged material) from sand mining are generally lower than estimated entrainment rates in Grays Harbor for the most of the species or taxa occurring in both locations. In most cases, the Estuary estimates were an order of magnitude lower. The three cases in which they were not lower were for speckled sanddab and smelt in Central Bay, which were higher, and for staghorn sculpin in Central Bay and starry flounder in the Delta, which were the same. Since the Grays Harbor data is based upon actual counts of fish entrained during hydraulic dredging, this would suggest that the estimates for San Francisco Bay might be low.

Our sand mining entrainment estimates, with the exception of yellowfin goby, are higher than those reported by Woodbury (2008) for Sonoma Marina. Woodbury's (2008) yellowfin goby entrainment estimates were higher than ours.

Table 4-1. Comparison of Adult and Juvenile Fish Entrained per Volume of Dredged Sand in Grays Harbor, WA to Central Bay and Delta Sand Mining

Taxa	Grays Harbor, WA	Sonoma Marina	Estimated Entrainment from Sand Mining in San Francisco Estuary	
		San Pablo Bay	Central Bay	Delta
	(Fish/cu yd)	(Fish/cu yd)	(Fish/cu yd)	(Fish/cu yd)
Northern anchovy	0.018	-	0.0004	0.00002
Anchovy (Clupeiformes)	0.001-0.008	-	-	-
Herring	0.008	-	0.0009	0.007
Starry Flounder	0.001-0.002	0.0012	-	0.001
English sole	0.006-0.035	-	0.02	-
Pacific sanddab	0.004-0.076	-	-	-
Speckled sanddab	0.003	-	0.04	-
Flatfish	0.001-0.028	-	-	-
Buffalo sculpin	0.006	-	-	-
Pacific staghorn sculpin	0.003-0.092	0.00003	0.008	0.001
Prickly sculpin	0.020	0.00014	-	-
Pacific sand lance	0.036-0.594	-	-	-
Sculpin	0.02	-	-	-
Surfperch	<0.001-0.001	-	0.006	-
Smelt	0.009	-	-	0.0003
Three-spined stickleback	0.004	-	-	-
Pacific tomcod	<0.001-0.008	-	-	-
Bay pipefish	0.008	0.00003	-	-
Yellowfin goby	-	0.029	-	0.001
Shimofuri goby	-	0.0004	-	-
Shokihaze goby	-	0.0003	-	0.002

[1]McGraw & Armstrong (1990);Larson & Moehl (1990); [2]Woodbury (2008)

4.1.2 Special Significance Species

To assess the effect of possible entrainment during sand mining on federally-or-state protected fish species and fish species of special significance to the Estuary, we examined the estimated annual entrainment for six species: Chinook salmon (*Oncorhynchus tshawytscha*), delta smelt (*Hypomesus transpacificus)*, green sturgeon (*Acipenser medirostris*), longfin smelt (*Spirinchus thaleichthys*), steelhead (*Oncorhynchus mykiss*), and splittail (*Pogonichthys macrolepidotus*) following the same protocols employed in this analysis for all other fish species (Tables 4-2 through 4-4). These estimates are shown on a monthly basis in Appendices C, D, and E.

Table 4-2: Annual Entrainment Estimates from Sand Mining for Sensitive Fish Species in Central Bay Mining Lease Areas

Common Name	Scientific Name	2000	2001	2002	2003	2004	2005	2006	2007	Avg. Entrainment, 2000-07	Combined Abundance Index, 2000-07	Proportion of AI Entrained Annually
Chinook salmon	*Oncorhynchus tshawytscha*	0	0	0	0	0	0	0	0	*0*	*81,333*	*0.0%*
Delta smelt	*Hypomesus transpacificus*	0	0	0	0	0	0	0	0	*0*	*0*	*0.0%*
Green sturgeon	*Acipenser medirostris*	0	0	0	0	0	0	0	0	*0*	*141*	*0.0%*
Longfin smelt	*Spirinchus thaleichthys*	1,603	146	1,622	477	508	931	46	662	*750*	*508,660*	*0.1%*
Steelhead	*Oncorhynchus mykiss*	0	0	0	0	0	0	0	0	*0*	*332*	*0.0%*
Splittail	*Pogonichthys macrolepidotus*	0	0	0	0	0	0	0	0	*0*	*0*	*0.0%*

Table 4-3. Entrainment Estimates from Sand Mining for Sensitive Fish Species in the Middle Ground Mining Lease Areas

Common Name	Scientific Name	2000	2001	2002	2003	2004	2005	2006	2007	Avg. Entrainment, 2000-07	Abundance Index, 2000-07	Proportion of AI Entrained Annually
Chinook salmon	*Oncorhynchus tshawytscha*	0	5	0	0	4	0	0	0	*1*	*44,854*	*0.00%*
Delta smelt	*Hypomesus transpacificus*	13	13	17	0	3	3	0	0	*6*	*20,242*	*0.03%*
Green sturgeon	*Acipenser medirostris*	0	0	0	0	0	0	0	0	*0*	*94*	*0.00%*
Longfin smelt	*Spirinchus thaleichthys*	99	44	154	50	146	42	34	9	*72*	*245,641*	*0.03%*
Steelhead	*Oncorhynchus*	0	0	0	0	0	0	0	0	*0*	*0*	*NA*

Common Name	Scientific Name	2000	2001	2002	2003	2004	2005	2006	2007	Avg. Entrainment, 2000-07	Abundance Index, 2000-07	Proportion of AI Entrained Annually
	mykiss											
Splittail	*Pogonichthys macrolepidotus*	7	9	9	5	0	2	33	13	*10*	*3,699*	*0.26%*

Table 4-4. Entrainment Estimates from Sand Mining for Sensitive Fish Species in Suisun Marsh Mining Lease Areas

Common Name	Scientific Name	2000	2001	2002	2003	2004	2005	2006	2007	Avg. Entrainment, 2000-07	Abundance Index, 2000-07	Proportion of AI Entrained Annually
Chinook salmon	*Oncorhynchus tshawytscha*	0	0	0	2	2	0	0	0	*1*	*22,526*	*0.01%*
Delta smelt	*Hypomesus transpacificus*	9	0	11	2	0	0	3	0	*3*	*33,527*	*0.01%*
Green sturgeon	*Acipenser medirostris*	0	0	0	0	1	0	1	0	*<1*	*181*	*0.13%*
Longfin smelt	*Spirinchus thaleichthys*	45	31	24	10	7	26	14	5	*20*	*58,417*	*0.03%*
Steelhead	*Oncorhynchus mykiss*	0	0	0	0	0	0	0	0	*0*	*1,004*	*0.00%*
Splittail	*Pogonichthys macrolepidotus*	0	0	0	0	0	0	0	0	*0*	*5,566*	*0.00%*

In the Central Bay mining lease sites, only longfin smelt is predicted to be entrained during sand mining operations. In the Middle Ground lease area, Chinook salmon, delta smelt, longfin smelt and splittail are predicted to be entrained. And in the Suisun Marsh mining leases, Chinook salmon, delta smelt, longfin smelt, and green sturgeon are predicted to be entrained during sand mining operations. In all three Bay mining lease areas, the percentage of entrained special status fish from sand mining operations is estimated to be less than 0.3% of the regional abundance index for that species of fish. Longfin smelt is the most entrained species with an average of 750, 72, and 20 individuals predicted to be entrained during 2000-2007 in Central Bay, Middle Ground, and Suisun Marsh lease areas, respectively. The other species each have 10 or fewer individuals being entrained per lease area.

As mentioned previously, these fish entrainment estimates are based on CDFG monthly trawl data, and are therefore subject to its limitations and should be viewed in this context. Additional information regarding each species of concern is presented below.

Chinook Salmon - NOAA, in their Biological Opinion for Sand Mining (NOAA, 2006) used a spreadsheet model that employed several variables, including estimated suction rates, the cross sectional area of the mining leases in Middle Ground Shoal and Suisun Marsh, the number of listed salmonid smolts that are expected to be near the demersal zone of these leases as they migrate to and from the sea and the Central Valley, the area surrounding the suction head where salmon smolts could be entrained, and the number of hours sand mining would be conducted during salmon migration. This model predicted that 143-273 salmon smolts might be entrained as a result of sand mining activities in the Delta leases.

Hanson (2006) entrained a total of eight salmon smolts in tests conducted at the former Benicia/Carquinez Strait mining lease. Hanson estimated a potential entrainment rate of 1.5 to 17.1 salmon smolts per 10,000 m^3 of water pumped, based on test results. Data from the Hanson (2006) report gathered using the CEMEX sand mining equipment and collected at the Benicia/Carquinez mining site were not used in the entrainment calculations prepared as part of this assessment for reasons that include: (1) concerns over entrainment differences between the dredging equipment used by CEMEX during the testing and the equipment that is used by Jericho/MTB and Hanson Aggregate, (2) operational parameters used during the testing, and (3) differences between the Benicia/Carquinez lease site, (no longer being used for sand mining), and the other Delta mining leases, which might have resulted in concentrating fish in the sand mining area. In addition, to accommodate the study design, the CEMEX mining equipment appears to have been operated at pump rates of 8% and 25% of maximum pump capacity or 11% and 31% of what is assumed to be normal operating pump capacity, assuming the pump is normally run at 80% maximum capacity. A reduced pump rate would be expected to reduce the suction of the dredge and therefore the number of fish that would be entrained during normal mining operations.

However, evaluation of the Hanson test results from this location does provide some additional qualitative insight into potential sand mining entrainment, especially Chinook salmon smolts. Of the eight salmon smolts entrained, seven were entrained during nighttime sampling. This is consistent with normal salmon movement behavior and the CDFG trawl results. During daylight hours, salmon typically swim in the upper water column and at night drop down into the demersal zone near the seafloor (NOAA, 2006). As a result, CDFG data would not be expected to exhibit high numbers of salmon in otter trawl data collected during daylight hours, but would report higher numbers in the midwater trawl data. This is the pattern we observe, as represented by comparing pelagic and demersal fish abundances (Appendix E). This entrainment assessment only used the demersal fish data from the CDFG otter trawl sampling, so it should be expected to underestimate salmon entrainment, since sand mining occurs during the day and night.

It should also be noted that for the Hanson (2006) study, although conducted between April and July during normal spring salmon migration to the sea, no test events were conducted during the peak migration period, which, based on Chinook salmon counts at Chipps Island (Hanson, 2006) occurred approximately between May 5th and May 19th. Since sand mining at the Delta mining leases does not currently have any date or time restrictions, it can be assumed that any mining activity that occurs during this peak migration period could be higher than estimated by this investigation.

Steelhead – Natural behavioral similarities between Chinook salmon and steelhead would suggest that this assessment's estimate of steelhead entrainment by sand mining in the Delta mining leases is probably underestimated similar to that of Chinook salmon, but on a smaller scale due to the lower abundances of steelhead within the lease areas.

Green Sturgeon – This assessment estimated that potentially one green sturgeon could be entrained periodically when population numbers were high in Suisun Marsh. Adult sturgeon, like adult salmon, can be expected to avoid entrainment (NOAA, 2006). However, all juveniles may not, depending on the mining location and mining operation. NOAA (2006), in the Biological Opinion for sand mining, estimated that up to one green sturgeon could be entrained by each mining company per year at the Delta mining sites.

Delta and Longfin smelt – Longfin smelt were estimated to be entrained at all three Bay mining regions, whereas delta smelt were only estimated to be entrained at Middle Ground Shoal and Suisun Marsh mining sites. Calculated entrainment estimates for longfin smelt were higher than for delta smelt, which is expected, since they are known to periodically swim throughout the water column whereas delta smelt remain at or near the water's surface (BLM, 2008).

Calculated annual entrainment estimates for delta smelt are probably low since delta smelt population numbers in the Delta have plummeted over the last few years, which would result in reduced capture in CDFG sampling programs and similarly reduced estimates in our calculations. Annual entrainment estimates for longfin smelt account for approximately 0.1% of the longfin smelt abundance index in Central Bay, and 0.03% in the Delta mining sites. Delta smelt annual entrainment estimates from sand mining account for 0.01%-0.03% of their annual abundance indices in the Delta.

Splittail – Splittail annual entrainment estimates from sand mining activities appear to only occur at the Middle Ground Shoal mining location and could account for up to 0.3% of the annual splittail abundance index in Suisun Bay.

4.1.3 Comparison of Entrainment Estimates with Fishery Landing Data

CDFG (2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008) commercial ocean fishing landing data for San Francisco was compiled for the period 2000-2007. This dataset reported landings, in pounds, for important commercial fish that spend at least part of their lifespan within San Francisco Bay, including Pacific herring (*Clupea pallasi*), herring roe, herring roe on kelp, California Bay shrimp (*Crangon franciscorum*), and Dungeness crab (*Cancer magister*). It is therefore possible to add some context to the above entrainment estimates for select fish, crab, and shrimp species by comparing entrainment estimates with actual commercial landings.

The only commercially important fish species, as defined by CDFG, predicted to be entrained through sand mining operations is Pacific herring. Pacific herring landed in San Francisco are currently marketed in one of three forms: as whole fish, as sac-roe retrieved from whole fish, and as roe on kelp, with herring sac-roe currently making up the vast majority of the marketable product (Table 4-5). It is notable that whole fish were brought to market in appreciable numbers in only one of the past eight years (2004). Estimated entrainment, calculated as the sum of adults and juveniles and larval fish adult equivalent loss (AEL) for each of the three regions is shown in

Table 4-6. During the CDFG study period of 2000 to 2007, the proportion of total abundance entrained for Pacific herring is estimated to have been less than 0.03% for all three regions combined. Based on these estimates, sand mining activities are not expected to have an appreciable effect on herring stocks or the herring roe fishery in the Estuary.

Table 4-5. Commercial Landings of Herring into San Francisco, 2000-07

Year	Herring (lbs)	Herring, sac-roe (lbs)	Herring, roe on kelp (lbs)
2000	13	7,276,197	189,225
2001	0	5,254,998	53,720
2002	0	6,773,658	90,661
2003	0	3,802,826	132,410
2004	77,040	2,974,319	12,489
2005	0	289,481	0
2006	0	1,490,854	520
2007	0	576,210	18,726
Avg.	***9,632***	***3,554,818***	***62,219***

Table 4-6. Estimated Annual Entrainment for Pacific Herring (*Clupea pallasi*) by Region and Comparison with Three-region Total Abundance Index

	Entrainment CB	Abundance Index, CB	Entrainment, MG	Abundance MG	Entrainment, SM	Abundance, SM	Total Entrainment	Total Abundance	Proportion of Abundance Entrained
2000	36	10,476,193	0	13,353	0	1,882	36	10,491,428	0.000%
2001	26	11,999,780	0	49,576	0	1,472	26	12,050,828	0.000%
2002	71	27,420,061	23	93,851	3	5,603	98	27,519,515	0.000%
2003	3,681	16,298,261	0	6,637	0	0	3,681	16,304,898	0.023%
2004	94	3,929,286	0	29,741	0	0	94	3,959,027	0.002%
2005	112	3,158,010	0	23,543	0	0	112	3,181,553	0.004%
2006	45	1,817,870	0	3,952	0	0	45	1,821,822	0.002%
2007	235	4,801,696	0	51,464	0	6,020	235	4,859,180	0.005%
Avg.	***538***	***9,987,645***	***0***	***0***	***0***	***0***	***0***	***0***	***0.000%***

CB = Central Bay; MG = Middle Ground; SM = Suisun Marsh

4.2 Megabenthic Invertebrates

Assorted megabenthic invertebrate taxa are entrained during sand mining activities in all three Bay mining regions. These include the more mobile caridean shrimp and Dungeness crabs as well as the less mobile sand anemones, tubeworms, hermit crabs, gastropods, seastars, and nudibranchs. Entrainment estimates from sand mining were calculated for Dungeness crabs and caridean shrimp. Sand anemones and hermit crabs were observed being entrained during a site visit aboard a sand miner by AMS personnel.

4.2.1 Dungeness Crab (*C. magister*)

Dungeness crab support a valuable commercial and sport fishery along the Central and North coasts of California, Oregon, Washington, and Alaska. It is the top fishery for San Francisco Bay ports, accounting for, on average, five to six million dollars in landings per year (CDFG, 2001-2008). In addition to its commercial and economic importance, Dungeness crab occupies ecological niches in both marine and estuary ecosystems and is ecologically important as both predator and prey at all life stages (Pauley, *et. al.*, 1989). The San Francisco Estuary plays a significant role in the Dungeness crab population in Central California coastal waters, which can be used by juveniles for rearing and growth prior to returning to the ocean as mature adults (Tasto, 1979, Pauley, *et. al.*, 1989). Juvenile crabs reared in the San Francisco Estuary are larger than their ocean reared counterparts (Pauley, *et. al.*, 1989), and may contribute more to commercial harvests as a result. The Dungeness crab population appears to undergo periodic multi-year cycles with high population abundances being followed by several years of low population numbers and concurrent low harvests (Pauley, *et. al.*, 1989). Juvenile Dungeness crabs are found throughout Central, South and North Bay, but are not typically observed in Suisun Bay and Suisun Marsh trawls.

In evaluating the potential effects of sand mining in the Estuary on Dungeness crab, three separate comparisons were conducted. The first compares adult equivalent loss (AEL) estimates for each crab juvenile stage against AEL estimates for all same age juveniles estimated to be inhabiting that Bay region in the same year. The second comparison looks at the potential effect of entrained juveniles on commercial crab harvests, as one indicator of the adult population, and the potential impact on the commercial fishery. The third and final comparison employs the methodology developed for estimating potential dredging impacts in Grays Harbor and the Columbia River.

Of the three Bay mining regions, Central Bay, Suisun Bay (Middle Ground Shoal), and Suisun Marsh, juvenile Dungeness crab are only found in significant numbers in Central Bay. Table 3-11 shows that in Suisun Bay, between 61 and 79 juvenile crabs are estimated to be entrained by mining operations at Middle Ground Shoal in years for which crabs are relatively abundant. For years in which the juvenile Dungeness crab population in the Estuary is low, as it has been for the last several years, the estimated annual entrainment of juvenile crabs is less than 1. Calculating an adult equivalent loss (AEL) for entrained juvenile crab at Middle Ground Shoal indicates than in higher juvenile abundant years, approximately one adult would be removed from the population (Table 3-12).

For the Central Bay mining lease sites, the entrainment of Dungeness crab juveniles is predicted to be much greater than that for Middle Ground Shoal (Table 3-9). Table 4-7 summarizes the AEL for both age classes of juvenile Dungeness crabs from sand mining operations in this Bay mining region. An average of approximately 851 adults would be removed annually from future populations of mature crabs. Compared to AEL estimates for all juvenile Dungeness crab age classes in Central Bay, this loss is estimated to represent between 0.2% and 1% of future adult populations over the eight-year study period.

Table 4-7. Quarterly AEL Entrainment Estimates for Dungeness Crab for All Ages in the Central Bay Mining Leases

	Winter	Spring	Summer	Fall	Annual Total	Abundance Index AEL	% of AI AEL
2000	298	84	47	365	794	78,836	1.0%
2001	213	423	298	25	959	173,511	0.6%
2002	610	293	134	170	1,207	173,694	0.7%
2003	882	229	77	42	1,229	146,997	0.8%
2004	217	1199	200	288	1,905	266,284	0.7%
2005	592	29	42	0	663	135,879	0.5%
2006	0	0	0	1	1	739	0.2%
2007	0	0	7	39	47	6,515	0.7%
Avg.	***352***	***282***	***101***	***116***	***851***	***122,807***	***0.6%***

In order to accurately understand the possible effect of proposed sand mining operations upon the Dungeness crab commercial fishery, it is necessary to compare juvenile entrainment data from several years with the adult population of a third year. For example, the AEL entrainment estimates of Year-0 aged juveniles in 2000 must be combined with the AEL entrainment estimates for Year-1+ aged juveniles from 2001 and compared to the estimated adult population in 2002 when both of these two sets of juveniles are expected to reach adult maturity. For the purposes of this evaluation we assumed that all crabs reached sexual maturity at age 2.

Tables 4-8 and 4-9 present AEL entrainment estimates for Dungeness crab in the Central Bay and Middle Ground Shoal mining leases, respectively, and compare them to the commercial landing data for the year each juvenile cohort was expected to reach sexual maturity and harvestable size. There are no calculations conducted for Suisun Marsh lease sites as there were no crabs collected in CDFG otter trawl samples associated with this region.

As indicated previously, the number of juvenile Dungeness crabs in Suisun Bay, specifically the Middle Ground Shoal mining lease, is estimated to be very low. As a consequence, the estimated AEL percentage of Dungeness crabs to San Francisco Bay commercial crab harvests between 2000 and 2007 is estimated to be equally small, representing less than 0.0001% of the landed catch, on average (Table 4-9). In Central Bay, the AEL loss of entrained juvenile crabs is estimated to range between 3 in 2007 and 1, 536 in 2006, representing <0.01% and 0.08%, respectively, of landed Dungeness crab at San Francisco ports. On average, it is estimated that sand mining activities in the Bay result in a loss of less than 0.1% of the annual crab harvests.

The third method used to estimate Dungeness crab entrainment was to employ the Dredging Impact Model (DIM) developed by Wainwright *et. al.* (1992) and McGraw *et. al*, (1988) for Grays Harbor, Washington. As previously discussed in more detail in the Methods section, Wainwright and McGraw developed a means of estimating juvenile Dungeness crab entrainment by suction dredge based on the volume of material dredged, the calendar quarter the dredging occurred, the density of crab in the area to be dredged (based on otter trawl sampling), and a calculated slope-of-entrainment (developed by comparing actual entrained juvenile crabs to trawl estimates).

Table 4-8. Relationship of Estimated Annual Entrainment AEL in Central Bay Mining Leases to Commercial Landings of Dungeness Crab in San Francisco Ports

Commercial Landings			Age 0 Juvenile Crabs		Age 1+ Juvenile Crabs		All Age Classes	Est. % of Landings Entrained
Commercial Harvest Year	Pounds (lbs)	# Crabs	Age Class Year	AEL Estimate	Age Class Year	AEL Estimate	Crab AEL	
2002	2,933,303	1,466,652	2000	330	2001	906	1,237	0.08%
2003	3,400,468	1,700,234	2001	77	2002	1,140	1,217	0.07%
2004	4,042,902	2,021,451	2002	210	2003	1,085	1,294	0.06%
2005	3,668,534	1,834,267	2003	191	2004	1,119	1,311	0.07%
2006	3,773,770	1,886,885	2004	856	2005	681	1,536	0.08%
2007	1,493,123	746,562	2005	3	2006	0	3	0.00%
Avg.	***3,563,795***	***1,781,898***						***0.07%***

[1] Assumes a 2-pound average crab weight

Table 4-9. Relationship of Estimated Annual Entrainment AEL in Middle Ground Shoal to Commercial Landings of Dungeness Crab in San Francisco Ports

Commercial Landings			Age 0 Juvenile Crabs		Age 1+ Juvenile Crabs		All Age Classes	Est. % of Landings Entrained
Commercial Harvest Year	Pounds (lbs)	# Crabs	Age Class Year	AEL Estimate	Age Class Year	AEL Estimate	Crab AEL	
2002	2,933,303	1,466,652	2000	0	2001	-	-	0.0000%
2003	3,400,468	1,700,234	2001	0	2002	0	0	0.0000%
2004	4,042,902	2,021,451	2002	1	2003	0	0	0.0000%
2005	3,668,534	1,834,267	2003	1	2004	0	1	0.0001%
2006	3,773,770	1,886,885	2004	0	2005	0	1	0.0000%
2007	1,493,123	746,562	2005	0	2006	0	0	0.0000%
Avg.	***3,563,795***	***1,781,898***						***0.0001%***

The primary difficulty with using this methodology for estimating Dungeness crab entrainment is that the slope-of-entrainment developed by Wainwright and McGraw appears to be highly site-specific and therefore only accurate for Grays Harbor, as suggested by Pacific International Engineering (2002) and Pearson *et. al.* (2002, 2003). We elected to include this method as one of the approaches used to calculate crab entrainment from sand mining because of its widespread use in past studies of Dungeness crab entrainment, and for comparison purposes.

Table 4-10 presents Dungeness crab entrainment estimates using the Dredge Impact Model (DIM) methodology outlined by Wainwright and McGraw, adjusted to reflect AEL. In comparing results from the two methods, we can see that that the DIM model results are typically an order of magnitude greater than those employed in this analysis, which were generated using a dredged-area method. Similar differences from the DIM method were reported by Pearson *et. al.* (2002) for the Columbia River. A higher estimate of Dungeness crab entrainment using the DIM methodology is also not unexpected given that: (1) the model was developed for maintenance dredging of a main navigation channel that is the primary means of crab movement between the Gray's Harbor estuary and the Pacific Ocean: and (2) dredging of the channel is intensely conducted over a short time period where entrainment could be greater.

Table 4-10. Comparison of Entrainment Adult Equivalence of *C. magister* as Estimated via Volumetric and Area-based Estimation Methods

	Alternate Estimating Methodology[1]					Primary Estimating Methodology[2]
	Q1 AEL (all age classes)	Q2 AEL (all age classes)	Q3 AEL (all age classes)	Q4 AEL (all age classes)	Total Annual AEL (all age classes)	Total Annual AEL (all age classes)
2000	3,028	1,261	311	3,015	7,616	794
2001	3,789	7,194	2,017	171	13,172	959
2002	8,913	4,310	860	1,596	15,679	1,207
2003	7,039	2,652	376	317	10,383	1,229
2004	1,515	14,860	1,261	2,310	19,946	1,905
2005	5,213	361	253	0	5,828	664
2006	0	0	0	9	9	2
2007	0	0	36	315	351	47
Avg.	***3,687***	***3,830***	***639***	***967***	***9,123***	***851***

[1] Dredge Impact Model (DIM) of Wainwright *et. al.* (1992) and McGraw *et. al.* (1988) for Grays Harbor, Washington; [2] Dredged-area method used in this study.

4.2.2 Caridean Shrimp

As discussed previously, of the seventeen species of Caridean shrimp observed by CDFG occurring in San Francisco Estuary waters, a total of nine dominate the local food web and mobile megabenthic community. Of these species, only *C. franciscorum* is commercially harvested for use as bait for sturgeon and striped bass sport fishing. All of the major shrimp species in the Estuary represent important prey for many fish species that inhabit the Estuary, such as green and white sturgeon, striped bass, leopard shark, Pacific staghorn sculpin, starry flounder, English sole, pile and rubberlip perch, Pacific tomcod, and brown rockfish (Baxter *et. al.*, 1999). As such, these shrimp represent a key component of the food web

Tables 4-11 through 4-13 provide annual entrainment estimates for sand mining activities in each of the three Bay mining regions for all major shrimp taxa present in those regions.

Table 4-11. Annual Entrainment Estimates for Caridean Shrimp in Central Bay Mining Leases

Shrimp Species	Years								Avg. Annual Entrainment Estimate	Avg. Annual Abundance Index (AI)	Avg. Annual % of AI Entrained
	1998	1999	2000	2001	2002	2003	2004	2005			
California bay (*C. franciscorum*)	209,895	95,177	38,891	35,854	23,227	18,411	38,156	16,616	*59,529*	*26,693,541*	*0.30%*
Blacktail (*C. nigricauda*)	268,290	213,965	636,842	1,322,282	1,733,614	1,984,895	1,145,171	862,446	*1,020,938*	*171,665,997*	*0.60%*
Blackspotted (*C. nigromaculata*)	3,871	4,407	7,146	5,627	699	1,310	2,461	4,681	*3,775*	*26,058,291*	*0.02%*
Stimpson coastal (*H. stimpsoni*)	3,323	7,003	8,756	26,674	100,221	118,725	11,966	53,786	*41,307*	*36,501,204*	*0.10%*
Smooth bay (*L. stylirostris*)	68,270	25,124	30,143	25,804	7,464	19,882	4,408	7,833	*23,616*	*2,510,281*	*1.70%*

Table 4-12. Annual Entrainment Estimates for Caridean Shrimp in Middle Ground Shoal Mining Lease

Shrimp Species	Years								Avg. Annual Entrainment Estimate	Avg. Annual Abundance Index (AI)	Avg. Annual % of AI Entrained
	1998	1999	2000	2001	2002	2003	2004	2005			
California bay (*C. franciscorum*)	31,529	42,680	68,033	57,236	53,621	44,952	46,091	44,907	*48,631*	*42,309,986*	*0.10%*
Blacktail (*C. nigricauda*)	0	0	0	21	27	0	33	0	*10*	*1,209,037*	*0.00%*
Blackspotted (*C. nigromaculata*)	0	0	0	0	0	0	0	0	*0*	*1,009*	*0.00%*
Stimpson coastal (*H. stimpsoni*)	0	0	0	0	0	0	0	0	*0*	*437*	*0.00%*
Oriental (*P. macrodactylus*)	58	58	133	1,077	479	194	283	170	*306*	*164,624*	*0.20%*

Table 4-13. Annual Entrainment Estimates for Caridean Shrimp Species in Suisun Marsh Mining Leases

Shrimp Species	Years								Avg. Annual Entrainment Estimate	Avg. Annual Abundance Index (AI)	Avg. Annual % of AI Entrained
	1998	1999	2000	2001	2002	2003	2004	2005			
California bay (*C. franciscorum*)	304	11,048	10,662	12,095	14,160	5,165	24,648	15,861	*11,743*	*5,160,171*	*0.20%*
Blackspotted (*C. nigromaculata*)	0	0	0	0	0	0	0	0	*0*	*0*	*0.00%*
Oriental (*P. macrodactylus*)	1,561	371	1,225	7,461	3728	2,410	1,608	746	*2,389*	*1,147,571*	*0.20%*

In the Central Bay mining leases, Blacktail shrimp are estimated to be the most frequently entrained species from sand mining activities, whereas California Bay shrimp are more heavily entrained in both Middle Ground Shoal and Suisun Marsh. Bay-wide, approximately 1.2 million shrimp are entrained by sand mining activities in the three Bay mining regions, representing an estimated 0.5% of the estimated shrimp abundance indices for those three regions (Tables 4-11 through 4-13). Of these 1.2 million shrimp, one million are Blacktail shrimp entrained at the Central Bay mining leases (Table 4-11).

Since California Bay shrimp are harvested commercially, a comparison of estimated entrainment numbers with commercial fish landing data was conducted. For purposes of converting number of shrimp to pounds of shrimp landed, based on an average length of 77 mm, (Baxter *et. al.*, 1999) we have assumed a conservative count of 30 shrimp per pound. The results of this comparison suggest that annual entrainment of California Bay shrimp through sand mining activities averages between 3% and 6% of the annual commercial landings (Table 4-14). Since this commercial fishery is market driven by the local demand for frozen and live shrimp for sport fishing, the annual landings do not represent either the potential fishery landings or the ability of local California Bay shrimp population to support a larger fishery.

Table 4-14. Comparison of Estimated California Bay Shrimp (*C. franciscorum*) Entrainment by Region with CDFG Annual Commercial Landings for San Francisco

Year	Entrainment, Central Bay	Entrainment, Middle Ground	Entrainment, Suisun Marsh	Sum of 3 Regions (No.)	Commercial Landings (lbs.)	Proportion of Landings Entrained annually
2000	38,891	68,033	10,662	117,586	82,816	4.9%
2001	35,854	57,236	12,095	105,185	94,078	3.9%
2002	23,227	53,621	14,160	91,008	70,798	4.4%
2003	18,411	44,952	5,165	68,528	85,264	2.8%
2004	38,156	46,091	24,648	108,895	66,424	5.6%
2005	16,616	44,907	15,861	77,384	52,055	5.1%
Avg.	**28,526**	**52,473**	**13,765**	**94,764**	**75,239**	**4.5%**

4.3 Comparison with Entrainment Estimates for Other Bay Anthropogenic Activities

Adverse environmental impacts to marine species and communities occur when any anthropogenic activity uses water from an estuary or the ocean. The primary sources of these impacts are from electric power generation, paper and pulp mills, petroleum refining and related industries, metal production, and desalination plants. In the majority of these cases, the marine waters are used for cooling electric generators, processing equipment, or manufactured products. In the case of desalination plants, the seawater itself is the raw material used to produce drinking water.

Because of the large volumes of water used in these operations, typically ranging between 200 and 2,500 million gallons of water per day (Foster & Steinbeck, 2008), the potential ecological effects of impingent and entrainment of marine organisms is a serious concern. Impingement occurs when fish are trapped against a cooling water intake structure's (CWIS) intake screens by the velocity of the flow, and they normally die as a result of starvation, asphyxiation, or serious injury. Entrainment occurs when fish eggs and larvae, plankton, and other invertebrates pass through a CWIS intake screen and are subjected to high temperatures, toxins in antifouling paint, and physical damage from passage through small condenser tubes. Improved CWIS designs have resulted in significant reductions in impinged fish at many of these facilities and operations, such as San Onofre Nuclear Power Generating station in San Diego, California (Steinbeck, 2008).

During hydraulic suction dredging, processes affecting the juvenile and adult fish and megabenthic invertebrates being entrained with the sand during mining activities are equivalent to those affecting the fish being impinged in a typical coastal power plant operation. Similarly, the effects of the entraining of larval fish and invertebrates being used to ballast the hopper barge and lift sand from the seafloor into the barge are comparable to those affecting the entrained taxa in the power plant comparison.

Three of the principal sources of entrainment and impingement of marine organisms in the Estuary are the Potrero, Pittsburgh, and Contra Costa power plants. Potential new sources of entrainment include a proposed desalination plant in Marin County (MMWD) and a proposed Regional Desalination plant in the East Bay. Current entrainment information is only available for the Mirant Potrero power plant in Central Bay (Tenera, 2005) and the Marin Municipal Water District's proposed desalination plant proposed for North Bay (Tenera, 2007).

Direct comparison of the estimated entrainment of juvenile and adult fish, shrimp, crabs, and larval fish and invertebrates is very difficult, since comparable information is not available. How many fish are being entrained (impinged) on the power plant's CWIS screens is not readily available so no direct comparison of adult fish to those affected can be made. In addition, the pilot plant operations, upon which the MMWD proposed desalination plant's entrainment estimates were based, did not have a large intake pipe and correspondingly large water flow, so no impingement was reported.

Commercial sand mining is estimated to pump approximately 5.8 billion gallons of water per year, which is approximately half the 11.0 billion gallons estimated for the MMWD proposed desalination plant and less than 10% of the 84.3 billion gallons of water potentially used by the Potrero power plant (Table 4-15). As a result of the significantly lower water volume used in sand mining, the estimated number of fish larvae and AEL adults is comparatively lower. Estimates for total fish larvae entrained for the three operations were 19 million for sand mining, 297 million for Potrero, and 233 million for the MMWD desalination plant. The MMWD desalination plant's relatively high entrainment estimate for the volume of water used relative to the Potrero Power Plant reflects the significant entrainment of Pacific herring. AEL estimates for those fish species representing 95% or more of the larvae of the identified local fish community were 14,884; 70,592; and 127,149 for sand mining, MMWD desalination plant, and the Potrero power plant, respectively (Table 4-15). Although both the Potrero and MMWD entrainment studies identified shrimp and crab larvae in the entrained water, neither calculated AEL estimates.

It should be noted that in the case of sand mining, the estimated larval entrainment occurring at the Central Bay mining leases is less than 10% of the estimated larval fish entrainment at either the Potrero power plant or the proposed MMWD desalination plant. In addition, the estimated

AEL of larval entrained fish during Central Bay mining activities is less than 10% of the adults estimated to be entrained with the sand.

Table 4-15. Comparison of Sand Mining Entrainment Estimates Between Commercial Sand Mining and San Francisco Bay Power and Desalination Plant Entrainment Estimates

		Est. Annual Water Use (gpy)	Total Est. # Fish Impinged	Total Est. # Larval Fish Entrained	Total Est. # Crabs Entrained	Total Est.# Shrimp Entrained	Total Est. AEL Fish Entrained
Commercial Sand Mining	Central Bay	5,091,170,660	129,777	17,920,241	6,805	1,149,195	12,070
	Middle Ground Shoal	433,459,424	1,375	595,606	2	48,947	2,726
	Suisun Marsh	239,110,524	238	841,632	0	14,132	88
	Total	5,763,740,608	131,390	19,357,479	6,807	1,212,244	14,884
Potrero Power Plant	-	84,310,000,000	NR	296,991,723	NR	NR	127,149
MMWD Proposed Desalination Plant	-	10,950,000,000	NR	233,272,707	NR	NR	70,592

NR = Not Reported

As shown in Table 3-1, bay goby, unidentified gobies, northern anchovy, Pacific herring, and yellowfin goby were the major larval fish entrained by both the Potrero power plant and the MMWD pilot desalination plant. In comparison, this assessment estimated that bay goby, northern anchovy, Pacific herring, speckled sanddab, and Pacific staghorn sculpin in Central Bay, Pacific herring and yellowfin goby in Middle Ground Shoal, and Shokihaze goby, and yellowfin goby in Suisun Marsh would be the most entrained fish species associated with sand mining activities.

Finally, because of the inherent operational differences between the Potrero power plant, the proposed MMWD desalination plant, and commercial sand mining, sand mining can be expected to have a greater entrainment impact on shrimp, Dungeness crab juveniles, and small juvenile and adult fish, like speckled sanddab, certain gobies (yellowfin, bay, and Shokihaze), Pacific herring, and northern anchovy. The potential for these species to occur in high densities immediately adjacent to or inside the intake pipe of a power plant or desalination plant is low, whereas sand mining is occurring in different locations within each lease on a daily basis.

4.4 Temporal Variation

It should be noted that appreciable differences in fish densities associated with CDFG trawling efforts were observable in many species over the course of the investigation's study period, 2000-2007. Should the dips in species densities seen in the last few years be more representative of future populations, then entrainment associated with sand mining operations could also be expected to drop. However, with declining populations would likely come an increase in concern over the number of sensitive species being entrained.

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Appendix A

Summary of Mining Effort Information Used in Analysis of Entrainment

Table A-1. Number of Sand Mining Events Conducted by Sand Mining Companies in Central Bay, Middle Ground, and Suisun Bay Leases, March 2002 to February 2003

Month	Central Bay	Middle Ground	Suisun Bay
March	43	13	5
April	46	14	12
May	55	15	6
June	58	14	5
July	67	20	5
August	71	16	4
September	54	17	4
October	64	16	4
November	52	15	1
December	43	4	0
January	41	0	9
February	36	11	3
Total	***630***	***155***	***58***

Table A-2. Total Sand Volume Dredged by Sand Mining Companies in Central Bay Lease Areas, 2000-07

Summary	Lease Area	Q1 Jan-Mar (cy)	Q2 Apr-May (cy)	Q3 Jun-Sep (cy)	Q4 Oct-Dec (cy)	Total (cy)
2007	All	261,015	232,558	297,580	251,149	1,042,302
2006	All	255,885	269,157	285,591	268,807	1,079,439
2005	All	259,114	295,212	347,265	320,981	1,222,572
2004	All	187,137	314,810	348,541	349,905	1,200,393
2003	All	227,008	286,645	288,198	269,949	1,071,800
2002	All	258,038	321,279	388,039	322,674	1,290,031
2001	All	340,486	434,954	385,352	288,572	1,449,364
2000	All	278,377	341,499	400,444	360,697	1,381,017

Table A-3. Total Sand Volume Dredged by Sand Mining Companies in Middle Ground Lease Areas, 2000-07

Lease Year	Lease Area	Q1 Jan-Mar (cy)	Q2 Apr-May (cy)	Q3 Jun-Sep (cy)	Q4 Oct-Dec (cy)	Total (cy)
2007	5733	0	0			0
2006	5733	15,442	3,561	0	0	19,003
2005	5733	0	4,326	18,594	12,204	35,125
2004	5733	2,011	17,596	14,274	18,470	52,351
2003	5733	9,559	3,817	4,001	5,543	22,921
2002	5733	5,974	5,730	10,222	14,172	36,099
2001	5733	0	0	No Activity	7,861	7,861
2000	5733	0	0	32,537	15,149	47,686

Table A-4. Total Sand Volume Dredged by Sand Mining Companies in Suisun Marsh Lease Areas, 2000-07

Lease Year	Lease Area	Q1 Jan-Mar (cy)	Q2 Apr-May (cy)	Q3 Jun-Sep (cy)	Q4 Oct-Dec (cy)	Total (cy)
2007	7781	1,314	29,230	36,837	29,535	96,916
2006	7781	0	24,097	50,085	4,778	78,960
2005	7781	29,740	26,350	43,113	0	99,203
2004	7781	14,692	24,483	2,699	22,066	63,940
2003	7781	30,459	25,812	57814	0	114,085
2002	7781	37,235	36,468	22,055	19,943	115,701
2001	7781	18,890	38,627	41,973	29,736	129,226
2000	7781	17,813	24,761	37,985	34,226	114,785

Appendix B

Larval Fish Entrainment Estimates from Recent San Francisco Bay Investigations

Table B-1 Larval Fish Entrainment Estimates for the Potrero Power Plant (Tenera, 2005) and the Marin Municipal Water District Proposed Desalinization Plant (Tenera, 2007)

		Potrero Power Plant 316(b) Entrainment Study		Marin Municipal Water District Pilot Desalinization Entrainment Study	
Common Name	Taxon	Estimated Annual # of Entrained Larvae	Percent of Total Entrainment (%)	Estimated Annual # of Entrained Larvae	Percent of Total Entrainment (%)
Bay goby	*Lepidogobius lepidus*	104,312,644	35.12	31,459	0.01
Gobies	Gobiidae unid.	65,237,852	21.97	1,860,969	0.80
Northern anchovy	*Engraulis mordax*	49,302,228	16.60	615,864	0.26
Pacific herring	*Clupea pallasii*	35,982,833	12.12	229,061,594	98.20
Yellowfin goby	*Acanthogobius. flavimamus*	29,230,697	9.84	565,866	0.24
White croaker	*Genyonemus lineatus*	6,281,538	2.12	15,596	0.01
California halibut	*Paralichthys californicus*	1,594,402	0.54	-	-
Pacific staghorn sculpin	*Leptocottus armatus*	933,538	0.31	64,166	0.03
Speckled sanddab	*Citharichthys stigmaeus*	656,840	0.22	-	-
Herrings and anchovies	Clupeiformes	466,877	0.16	-	-
Larval fishes, damaged	larval fish - damaged	357,748	0.12	764,133	0.33
Pacific sand lance	*Ammodytes hexapterus*	315,914	0.11	-	-
Rockfishes	*Sebastes* spp.	315,953	0.12	8,216	>0.01
Sand sole	*Psettichthys melanostictus*	279,656	0.09	-	-
Starry flounder	*Platichthys stellatus*	-	-	8,333	>0.01
Flounders	Pleuronectidae unid.	242,949	0.08	-	-
Diamond turbot	*Hypsopsetta guttulata*	196,164	0.07	23,374	0.01
Larval fishes	larval/post-larval fish, unid.	190,943	0.06	23,631	0.01
Croakers	Sciaenidae unid.	134,360	0.05	-	-
Pipefishes	*Syngnathus* spp.	120,780	0.04	-	-
Jacksmelt	*Atherinopsis californiensis*	97,341	0.03	-	-
Monkeyface eel	*Cebidichthys violaceus*	73,393	0.02	8,255	>0.01
Silversides	Atherinidae unid.	62,648	0.02	7,543	>0.01
Sculpins	*Oligocottus* spp.	61,773	0.02	-	-
Prickle backs	Stichaeidae unid.	60,643	0.02	-	-
Bay pipefish	*Syngnathus leptorhynchus*	45,588	0.02	-	-
Smelts	Osmeridae unid.	38,698	0.01	106,607	0.05
Pacific sanddab	*Citharichthys sordidus*	36,462	0.01	-	-
Sculpins	Cottidae unid.	34,732	0.01	-	-
Prickly sculpin	*Cottus asper*	-	-	84,676	0.04
Blackeye goby	*Coryphopterus nicholsi*	33,936	0.01	-	-

		Potrero Power Plant 316(b) Entrainment Study		Marin Municipal Water District Pilot Desalinization Entrainment Study	
Common Name	**Taxon**	**Estimated Annual # of Entrained Larvae**	**Percent of Total Entrainment (%)**	**Estimated Annual # of Entrained Larvae**	**Percent of Total Entrainment (%)**
Northern lampfish	*Stenobrachius leucopsarus*	31,386	0.01	-	-
English sole	*Parophrys vetulus*	31,075	0.01	-	-
Cabezon	*Scorpaenichthys marmoratus*	22,687	0.01	-	-
Snailfishes	Cyclopteridae unid.	21,161	0.01	-	-
Queenfish	*Seriphus politus*	18,775	0.01	-	-
Rock sole	*Pleuronectes bilineatus*	17,449	0.01	-	-
Sculpins	*Clinocottus* spp.	17,082	0.01	22,426	0.01
Topsmelt	*Atherinops affinis*	16,586	0.01	-	-
Longjaw mudsucker	*Gillichthys mirabilis*	15,723	0.01	-	-
Clinid kelpfishes	*Gibbonsia* spp.	15,692	0.01	-	-
Blennies	*Hypsoblennius* spp.	15,316	0.01	-	-
Flatfishes	Pleuronectiformes unid.	13,400	<0.01	-	-
Clingfishes	*Gobiesox* spp.	6,166	<0.01	-	-
Lefteye flounders & sanddabs	Paralichthyidae unid.	5,730	<0.01	-	-
Giant kelpfish	*Heterostichus rostratus*	5,377	<0.01	-	-
Greenlings	Hexagrammidae unid.	5,377	<0.01	-	-
Lingcod	*Ophiodon elongatus*	5,226	<0.01	-	-
Sculpins	*Artedius* spp.	4,783	<0.01	-	-
Butter sole	*Pleuronectes isolepis*	4,498	<0.01	-	-
Snailfishes	*Liparis* spp.	4,216	<0.01	-	-
Gunnels	Pholididae unid.	4,014	<0.01	-	-
Codfishes	Gadidae	3,936	<0.01	-	-
Brown Irish lord	*Hemilepidotus spinosus*	3,505	<0.01	-	-
Sanddabs	*Citharichthys* spp.	3,433	<0.01	-	-
Total Fishes		***296,991,723***		***233,272,708***	

Appendix C

Summarized Data from Fish Entrainment Studies in San Pablo Bay And Western Delta (Woodbury, 2008) and Suisun Bay (Hanson, 2006)

Table C-1. Number of Fish Entrained in Middle Ground and Suisun Marsh Lease Areas (Source: Hanson, 2006)

Date	Region	Mining Company	# Samples	Chinook Salmon	Northern Anchovy	Pacific Staghorn Sculpin	Starry Flounder	Splittail	Yellowfin Goby	Three-spine Stickleback	Striped Bass	Vol Sampled (m3)
4/26/06	Suisun Marsh	Hanson	6	-	-	-	-	-	-	-	1	8,395
5/2/06	Suisun Marsh	Hanson	12	-	-	-	-	-	-	-	-	15,360
6/1/06	Middle Ground	Jericho /MTB	12	-	-	-	-	-	1	-	-	10,896
6/2/06	Middle Ground	Jericho /MTB	12	-	-	-	-	1	1	1	-	10,896
6/8/06	Suisun Marsh	Hanson	7	-	-	-	-	-	-	-	-	9,961
6/9/06	Suisun Marsh	Hanson	8	-	-	-	-	-	-	-	-	11,384
	Total		**57**	**0**	**0**	**0**	**0**	**1**	**2**	**1**	**1**	**66,892**
5/23/06	Benicia	CEMEX	4	4	-	-	-	10	-	-	-	282
5/24/06	Benicia	CEMEX	16	1	2	-	-		-	-	-	3,570
6/7/06	Benicia	CEMEX	16	1		-	-	4	-	-	-	4,136
6/8/06	Benicia	CEMEX	7	2	-	1	1	4	-	-	-	2,115
	Total		**43**	**8**	**2**	**1**	**1**	**18**	**0**	**0**	**0**	**10,103**

Only the fish entrainment data collected from the Jericho/MTB and Hanson Aggregate vessels for samples collected in Middle Ground and Suisun Marsh lease areas is reported since the CEMEX/RMC vessel is no longer engaged in sand mining and the Carquinez sand mining lease is not included in the requested lease renewals that are the basis of this assessment.

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Table C-2. Fish Entrainment Data from Sonoma Marina Dredging Study (Woodbury, 2008).

Study Information	
Survey Date:	**12/12/2007-01/31/2008**
Volume Sand Dredged	43,330 cubic yards
Dredging Hours of Study	168 hours

Fish Species Entrained	# Entrained
Yellowfin goby	1235
Shimofuri goby	17
Shokihaze goby	13
Prickly sculpin	6
Starry Flounder	5
Atherinidae (silversides)	2
Bay pipefish	1
Pacific staghorn sculpin	1
TOTAL	**1280**
	7.6 fish/hr
	30 fish/1000 cubic yards of dredged material

Appendix D

Central Bay Regional Abundance Indices for All Fish Taxa;

Entrainment Estimates for Most Abundant and Sensitive Species in Central Bay Mining Leases

Table D-1. Total Abundance Indices for All Fish Taxa Collected by IEP in Central Bay

Common Name	Scientific Name	Abundance, Demersal Habitat	Abundance, Pelagic Zone	Total Abundance Index	% of Total
Northern Anchovy	*Engraulis mordax*	0	156,342,341	156,342,341	75.8%
Pacific Herring	*Clupea pallasii*	114,919	9,872,726	9,987,645	4.8%
Speckled Sanddab	*Citharichthys stigmaeus*	9,379,637	4,320	9,383,958	4.5%
Bay Goby	*Lepidogobius lepidus*	7,663,975	12,460	7,676,435	3.7%
Plainfin Midshipman	*Porichthys notatus*	5,749,682	33,600	5,783,282	2.8%
English Sole	*Parophrys vetulus*	4,757,233	3,057	4,760,291	2.3%
Pacific Sardine	*Sardinops sagax*	10,202	2,736,584	2,746,786	1.3%
Shiner Perch	*Cymatogaster aggregata*	1,595,338	649,176	2,244,513	1.1%
Pacific Staghorn Sculpin	*Leptocottus armatus*	1,822,135	3,696	1,825,832	0.9%
Jacksmelt	*Atherinopsis californiensis*	0	987,004	987,004	0.5%
White Croaker	*Genyonemus lineatus*	440,843	93,640	534,483	0.3%
Longfin Smelt	*Spirinchus thaleichthys*	414,472	94,188	508,660	0.2%
Topsmelt	*Atherinops affinis*	1,872	468,170	470,042	0.2%
Pacific Pompano	*Peprilus simillimus*	162	438,332	438,494	0.2%
Walleye Surfperch	*Hyperprosopon argenteum*	30,473	272,406	302,879	0.1%
Pacific Tomcod	*Microgadus proximus*	248,025	3,562	251,587	0.1%
Brown Rockfish	*Sebastes auriculatus*	231,358	0	231,358	0.1%
Cheekspot Goby	*Ilypnus gilberti*	216,850	434	217,284	0.1%
Bonyhead Sculpin	*Artedius notospilotus*	198,156	0	198,156	0.1%
California Grunion	*Leuresthes tenuis*	0	188,088	188,088	0.1%
Bay Pipefish	*Syngnathus leptorhynchus*	166,073	930	167,004	0.1%
Saddleback Gunnel	*Pholis ornata*	84,339	0	84,339	0.0%
Pacific Sanddab	*Citharichthys sordidus*	82,374	1,350	83,724	0.0%
Showy Snailfish	*Liparis pulchellus*	81,909	0	81,909	0.0%
Chinook Salmon	*Oncorhynchus tshawytscha*	0	81,333	81,333	0.0%
California Tonguefish	*Symphurus atricaudus*	70,305	0	70,305	0.0%
California Halibut	*Paralichthys californicus*	62,710	4,789	67,499	0.0%
American Shad	*Alosa sapidissima*	4,526	55,290	59,817	0.0%
Chameleon Goby	*Tridentiger trigonocephalus*	51,599	0	51,599	0.0%
Yellowfin Goby	*Acanthogobius flavimanus*	49,651	886	50,537	0.0%
White Seaperch	*Phanerodon furcatus*	16,369	32,966	49,335	0.0%
Curlfin Sole	*Pleuronichthys decurrens*	48,302	0	48,302	0.0%
Brown Smoothhound	*Mustelus henlei*	41,836	2,729	44,565	0.0%
Lingcod	*Ophiodon elongatus*	31,279	863	32,142	0.0%
Big Skate	*Raja binoculata*	26,056	2,291	28,347	0.0%
Buffalo Sculpin	*Enophrys bison*	27,057	0	27,057	0.0%
Whitebait Smelt	*Allosmerus elongatus*	2,923	20,923	23,847	0.0%
Threadfin Shad	*Dorosoma petenense*	1,661	18,342	20,003	0.0%
Bat Ray	*Myliobatis californica*	9,959	8,270	18,229	0.0%
Sand Sole	*Psettichthys melanostictus*	17,349	0	17,349	0.0%
Black Perch	*Embiotoca jacksoni*	13,065	788	13,853	0.0%
Starry Flounder	*Platichthys stellatus*	12,314	1,378	13,692	0.0%
Kelp Greenling	*Hexagrammos decagrammus*	11,862	734	12,596	0.0%

Common Name	Scientific Name	Abundance, Demersal Habitat	Abundance, Pelagic Zone	Total Abundance Index	% of Total
Pacific Sand Lance	*Ammodytes hexapterus*	11,867	0	11,867	0.0%
Pygmy Poacher	*Odontopyxis trispinosa*	11,074	0	11,074	0.0%
Dwarf Perch	*Micrometrus minimus*	10,180	0	10,180	0.0%
Spotted Cusk Eel	*Chilara taylori*	8,159	0	8,159	0.0%
Arrow Goby	*Clevelandia ios*	7,089	0	7,089	0.0%
Rubberlip Seaperch	*Rhacochilus toxotes*	5,758	0	5,758	0.0%
Leopard Shark	*Triakis semifasciata*	5,065	562	5,627	0.0%
Diamond Turbot	*Pleuronichthys guttulatus*	4,968	562	5,530	0.0%
Striped Bass	*Morone saxatilis*	733	4,257	4,990	0.0%
River Lamprey	*Lampetra ayresii*	3,677	475	4,152	0.0%
Pile Perch	*Rhacochilus vacca*	1,432	1,242	2,674	0.0%
Yellow Eye Rockfish	*Sebastes ruberrimus*	2,516	0	2,516	0.0%
Cabezon	*Scorpaenichthys marmoratus*	2,267	0	2,267	0.0%
Threespine Stickleback	*Gasterosteus aculeatus*	0	1,594	1,594	0.0%
Barred Surfperch	*Amphistichus argenteus*	487	996	1,483	0.0%
Pacific Lamprey	*Lampetra tridentata*	1,112	0	1,112	0.0%
Dover Sole	*Microstomus pacificus*	1,045	0	1,045	0.0%
Thornback	*Platyrhinoidis triseriata*	600	421	1,022	0.0%
Onespot Fringehead	*Neoclinus uninotatus*	1,014	0	1,014	0.0%
Queenfish	*Seriphus politus*	0	981	981	0.0%
Pacific Electric Ray	*Torpedo californica*	0	961	961	0.0%
Striped Seaperch	*Embiotoca lateralis*	950	0	950	0.0%
Spiny Dogfish	*Squalus acanthias*	916	0	916	0.0%
Slipskin Snailfish	*Liparis fucensis*	829	0	829	0.0%
Shokihaze Goby	*Tridentiger barbatus*	808	0	808	0.0%
Surf Smelt	*Hypomesus pretiosus*	0	695	695	0.0%
Hornyhead Turbot	*Pleuronichthys verticalis*	686	0	686	0.0%
Padded Sculpin	*Artedius fenestralis*	673	0	673	0.0%
Scalyhead Sculpin	*Artedius harringtoni*	563	0	563	0.0%
Night Smelt	*Spirinchus starksi*	513	0	513	0.0%
Shimofuri Goby	*Tridentiger bifasciatus*	511	0	511	0.0%
Vermillion Rockfish	*Sebastes miniatus*	433	0	433	0.0%
Snapper Spp	*Lutjanus*	359	0	359	0.0%
Steelhead	*Oncorhynchus mykiss*	0	332	332	0.0%
Redtail Surfperch	*Amphistichus rhodoterus*	0	330	330	0.0%
Bluegill	*Lepomis macrochirus*	269	0	269	0.0%
Spotfin Surf Perch	*Hyperprosopon anale*	190	0	190	0.0%
Bocaccio	*Sebastes paucispinis*	170	0	170	0.0%
White Sturgeon	*Acipenser transmontanus*	147	0	147	0.0%
Brown Irish Lord	*Hemilepidotus spinosus*	141	0	141	0.0%
Green Sturgeon	*Acipenser medirostris*	141	0	141	0.0%
Mussel Blenny	*Hypsoblennius jenkinsi*	135	0	135	0.0%

Table D-2. Estimated Entrainment, Northern Anchovy, Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***

Table D-3. Estimated Entrainment, Pacific Herring, Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	17	0	0	0	0	11	0	0	0	0	0	0	28
2001	0	20	-	0	0	0	0	0	0	0	0	0	20
2002	-	29	0	0	0	0	13	0	0	13	0	0	56
2003	0	0	0	112	0	2,583	37	101	0	0	0	0	2,833
2004	0	0	37	0	0	21	0	0	0	0	7	9	74
2005	0	9	0	0	0	16	0	38	13	0	0	11	88
2006	0	0	0	0	0	35	0	0	0	0	0	0	35
2007	159	10	0	10	0	0	0	0	0	0	0	0	179
Avg.	***25***	***9***	***5***	***15***	***0***	***333***	***6***	***17***	***2***	***2***	***1***	***3***	***414***

Table D-4. Estimated Entrainment, Speckled Sanddab, Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	2,597	3,141	763	3,030	3,159	15,074	2,495	802	1,898	3,374	496	9,768	46,598
2001	15,798	11,833		5,833	7,329	7,727	2,812	1,636	1,533	4,308	2,760	10,761	72,329
2002		5,008	13,205	8,145	10,191	8,427	4,801	5,121	1,896	2,849	1,682	1,452	62,777
2003	2,061	4,190	1,835	5,721	11,470	4,087	4,643	5,562	5,645	2,290	1,605	1,254	50,364
2004	803	1,756	2,993	3,500	5,961	2,927	729	2,183	993	545	367	696	23,453
2005	525	1,061	1,351	957	1,333	2,194	911	1,500	349	257	388	1,111	11,939
2006	777	882	1,487	452	1,848	1,296	460	448	110	166	37	280	8,243
2007	2,313	1,956	124	1,682	4,746	3,914	1,661	169	375	105	240	407	17,692
Avg.	*3,554*	*3,728*	*3,108*	*3,665*	*5,755*	*5,706*	*2,314*	*2,178*	*1,600*	*1,737*	*947*	*3,216*	*36,674*

Table D-5. Estimated Entrainment, Bay Goby, Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	21	109	12	24	1,350	227	3,683	747	1,879	886	217	1,881	11,035
2001	248	76		527	1,772	10,059	5,936	8,645	1,917	2,021	849	2,258	34,307
2002		715	197	4,174	2,443	7,620	2,949	7,643	5,005	2,973	3,624	537	37,880
2003	1,790	644	447	62	8,151	3,423	3,400	31,296	20,791	2,618	1,031	1,964	75,618
2004	112	24	99	0	48	4,007	4,067	7,311	310	1,267	76	66	17,386
2005	335	70	171	11	273	503	540	1,790	351	13	54	244	4,355
2006	41	144	50	0	693	680	8,141	3,999	2,068	2,092	28	494	18,430
2007	484	753	43	71	30	5,612	6,704	3,870	921	1,313	1,429	704	21,934
Avg.	***433***	***317***	***145***	***609***	***1,845***	***4,016***	***4,428***	***8,163***	***4,155***	***1,648***	***914***	***1,018***	***27,618***

Table D-6. Estimated Entrainment, Plainfin Midshipman, Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	31	6	0	0	87	186	469	69	4,061	1,260	10	607	6,787
2001	0	0	-	14	92	205	521	385	4,841	3,009	1,398	543	11,008
2002	-	70	196	677	462	745	2,398	3,584	7,643	6,610	5,120	134	27,639
2003	15	0	119	120	91	456	288	852	11,403	9,896	468	331	24,040
2004	0	72	9	77	100	301	195	263	15,975	7,803	873	102	25,771
2005	12	107	181	112	352	110	124	1,012	380	134	754	500	3,777
2006	70	9	338	0	67	87	121	507	361	6,291	14	310	8,175
2007	134	204	9	550	143	325	6,620	711	7,753	87,385	7,569	550	111,953
Avg.	***37***	***59***	***122***	***194***	***174***	***302***	***1,342***	***923***	***6,552***	***15,299***	***2,026***	***385***	***27,393***

Table D-7. Estimated Entrainment, English Sole, Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	7	155	83	281	3,250	6,152	2,676	2,324	5,180	370	693	1,737	22,909
2001	407	282	-	1,903	30,317	19,100	8,311	5,059	141	673	539	370	67,102
2002	-	195	210	276	901	3,680	2,344	3,250	3,013	1,238	450	467	16,027
2003	638	1,864	2,264	957	5,253	2,204	2,822	7,689	6,026	2,192	743	429	33,081
2004	169	67	24	549	583	3,715	906	2,776	5,025	1,408	626	247	16,094
2005	213	41	62	11	53	110	382	389	427	269	99	220	2,275
2006	27	55	0	0	14	60	125	0	28	0	0	0	309
2007	125	24	9	34	641	115	7,002	3,371	4,351	4,589	503	185	20,948
Avg.	***227***	***335***	***379***	***501***	***5,126***	***4,392***	***3,071***	***3,107***	***3,024***	***1,342***	***457***	***457***	***22,343***

Table D-8. Estimated Entrainment, Pacific Sardine, Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	-	0	0	0	0	0	0	0	0	0	0
2002	--	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	23	23
2004	10	0	11	0	0	0	0	0	0	0	0	0	20
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	385	0	0	0	0	0	0	0	0	0	385
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***1***	***0***	***57***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***3***	***54***

Table D-9. Estimated Entrainment, Shiner Perch, Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	99	576	0	15	23	14	126	113	81	394	196	399	2,035
2001	18	92	-	49	501	424	385	618	672	1,243	188	3,107	7,298
2002	--	612	161	589	30	144	232	873	644	72	1,739	558	5,655
2003	688	1,202	691	370	49	102	89	497	115	1,674	2,784	262	8,523
2004	774	720	364	221	179	1,625	378	1,327	510	834	89	848	7,869
2005	977	356	1,098	516	190	234	66	56	45	64	0	183	3,785
2006	95	443	1,062	74	0	231	20	0	62	113	76	1,477	3,653
2007	2,410	1,227	630	136	446	19	1,128	316	340	194	312	438	7,596
Avg.	***723***	***653***	***572***	***246***	***177***	***349***	***303***	***475***	***309***	***573***	***673***	***909***	***5,802***

Table D-10. Estimated Entrainment, Pacific Staghorn Sculpin, Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	14	122	26	168	177	479	537	909	877	419	62	251	4,042
2001	89	78		38	107	619	7,623	3,237	3,508	654	592	325	16,870
2002		58	175	132	177	4,319	6,093	14,000	1,560	1,478	520	59	28,571
2003	41	86	90	173	353	1,527	2,797	6,137	2,493	555	222	80	14,552
2004	28	38	37	76	279	1,205	371	696	1,433	836	76	0	5,076
2005	23	34	84	98	77	466	69	245	218	143	36	0	1,492
2006	68	18	14	0	14	152	346	16	50	311	0	0	990
2007	41	0	0	33	438	248	6,829	608	395	371	170	59	9,192
Avg.	***43***	***54***	***61***	***90***	***203***	***1,127***	***3,083***	***3,231***	***1,317***	***596***	***210***	***97***	***10,098***

Table D-11. Estimated Entrainment, Longfin Smelt (Sensitive Species), Central Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	51	0	0	0	141	266	447	460	13	31	10	184	1,603
2001	0	20	-	14	0	13	61	0	27	0	0	9	146
2002	-	31	0	18	44	106	389	347	61	426	163	38	1,622
2003	30	0	16	0	191	13	22	40	9	45	0	111	477
2004	104	67	0	0	0	71	87	38	20	35	78	9	508
2005	29	9	26	26	69	58	195	299	27	98	49	46	931
2006	0	0	0	0	14	47	644	214	1021	414	19	46	2,419
2007	27	60	9	0	0	0	93	271	107	78	17	0	662
Avg.	***34***	***23***	***7***	***7***	***57***	***72***	***242***	***209***	***161***	***141***	***42***	***56***	***1,046***

Appendix E

Suisun Bay Abundance Indices for All Fish Taxa;

Entrainment Estimates for Most Abundant and Sensitive Species in Middle Ground Mining Lease

Table E-1. Total Abundance Indices for All Fish Taxa Collected by IEP in Middle Ground

Common Name	Scientific Name	Abundance, Demersal Habitat	Abundance, Pelagic Zone	Total Abundance	% Total
Striped Bass	*Morone saxatilis*	191,625	153,318	344,943	20.8%
Northern Anchovy	*Engraulis mordax*	0	312,724	312,724	18.9%
Longfin Smelt	*Spirinchus thaleichthys*	52,152	193,489	245,641	14.8%
Yellowfin Goby	*Acanthogobius flavimanus*	135,088	16,728	151,817	9.2%
Shokihaze Goby	*Tridentiger barbatus*	122,743	2,344	125,086	7.5%
American Shad	*Alosa sapidissima*	4,393	108,782	113,174	6.8%
Pacific Staghorn Sculpin	*Leptocottus armatus*	80,031	3,221	83,251	5.0%
Starry Flounder	*Platichthys stellatus*	50,965	3,246	54,211	3.3%
Chinook Salmon	*Oncorhynchus tshawytscha*	444	44,410	44,854	2.7%
Plainfin Midshipman	*Porichthys notatus*	26,386	7,900	34,286	2.1%
Pacific Herring	*Clupea pallasii*	1,365	32,650	34,015	2.1%
Threadfin Shad	*Dorosoma petenense*	1,668	20,826	22,494	1.4%
Delta Smelt	*Hypomesus transpacificus*	2,302	17,939	20,242	1.2%
Splittail	*Pogonichthys macrolepidotus*	3,699	14,537	18,235	1.1%
English Sole	*Parophrys vetulus*	10,033	164	10,197	0.6%
Shimofuri Goby	*Tridentiger bifasciatus*	6,141	1,204	7,345	0.4%
Threespine Stickleback	*Gasterosteus aculeatus*	4,587	2,600	7,187	0.4%
River Lamprey	*Lampetra ayresii*	3,882	179	4,061	0.2%
Pacific Lamprey	*Lampetra tridentata*	3,735	72	3,807	0.2%
White Sturgeon	*Acipenser transmontanus*	1,281	1,566	2,847	0.2%
Bay Goby	*Lepidogobius lepidus*	2,529	196	2,725	0.2%
Speckled Sanddab	*Citharichthys stigmaeus*	2,266	150	2,416	0.1%
Topsmelt	*Atherinops affinis*	0	2,112	2,112	0.1%
Common Carp	*Cyprinus carpio*	265	1,557	1,822	0.1%
Prickly Sculpin	*Cottus asper*	1,308	0	1,308	0.1%
Steelhead	*Oncorhynchus mykiss*	0	681	681	0.0%
White Catfish	*Ameiurus catus*	653	0	653	0.0%
California Halibut	*Paralichthys californicus*	623	0	623	0.0%
Sand Sole	*Psettichthys melanostictus*	594	0	594	0.0%
White Croaker	*Genyonemus lineatus*	573	0	573	0.0%
Jacksmelt	*Atherinopsis californiensis*	0	543	543	0.0%
Shiner Perch	*Cymatogaster aggregata*	426	92	518	0.0%
Cheekspot Goby	*Ilypnus gilberti*	304	0	304	0.0%
Diamond Turbot	*Pleuronichthys guttulatus*	298	0	298	0.0%
Tule Perch	*Hysterocarpus traskii*	297	0	297	0.0%
Channel Catfish	*Ictalurus punctatus*	268	0	268	0.0%
Arrow Goby	*Clevelandia ios*	220	0	220	0.0%
Bluegill	*Lepomis macrochirus*	0	192	192	0.0%
Mississippi Silverside	*Menidia audens*	0	146	146	0.0%
Brown Smoothhound	*Mustelus henlei*	116	0	116	0.0%
Goldfish	*Carassius auratus*	110	0	110	0.0%
Green Sturgeon	*Acipenser medirostris*	94	0	94	0.0%
Bonyhead Sculpin	*Artedius notospilotus*	79	0	79	0.0%

Common Name	Scientific Name	Abundance, Demersal Habitat	Abundance, Pelagic Zone	Total Abundance	% Total
Rainwater Killifish	*Lucania parva*	78	0	78	0.0%
Hardhead	*Mylopharodon conocephalus*	0	74	74	0.0%
Pacific Pompano	*Peprilus simillimus*	0	65	65	0.0%
Pacific Sanddab	*Citharichthys sordidus*	40	0	40	0.0%

Table E-2. Estimated Entrainment, Striped Bass, Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	11	11	5	4	5	12	20	41	12	13	40	176
2001	0	42	-	0	0	67	0	33	57	45	23	39	305
2002	-	96	35	25	9	5	7	34	16	0	41	11	279
2003	0	25	5	33	0	53	37	152	127	11	9	9	459
2004	0	23	29	33	21	11	0	32	41	27	4	21	241
2005	0	17	0	10	0	22	326	25	35	91	23	2	550
2006	0	8	10	15	13	6	762	150	249	115	30	3	1,361
2007	0	45	10	20	4	14	60	32	39	36	18	0	276
Avg.	***0***	***33***	***14***	***18***	***6***	***23***	***151***	***60***	***76***	***42***	***20***	***16***	***456***

Table E-3. Estimated Entrainment, Northern Anchovy, Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	-	0	0	0	0	0	0	0	0	0	0
2002	-	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***

Table E-4. Estimated Entrainment, Longfin Smelt (Sensitive Species), Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	15	0	5	12	0	15	9	0	29	10	5	99
2001	0	0	-	7	0	26	6	0	0	0	0	5	44
2002	-	2	0	0	6	0	73	6	15	8	29	15	154
2003	0	8	0	7	4	12	0	4	0	5	9	1	50
2004	0	5	68	0	0	0	0	0	0	31	30	12	146
2005	0	27	3	7	0	0	5	0	0	0	0	1	42
2006	0	0	4	0	0	0	19	0	4	7	0	0	34
2007	0	0	0	0	0	0	0	0	6	0	4	0	9
Avg.	**0**	**7**	**11**	**3**	**3**	**5**	**15**	**2**	**3**	**10**	**10**	**5**	**72**

Table E-5. Estimated Entrainment, Yellowfin Goby, Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	4	2	12	9	69	376	209	8	112	4	5	810
2001	0	26	-	21	0	0	10	37	0	12	32	11	148
2002	-	0	0	3	0	5	0	0	0	0	20	0	28
2003	0	14	11	0	11	9	4	4	19	13	3	7	96
2004	0	3	31	0	0	0	62	25	5	16	7	1	151
2005	0	7	16	11	5	17	8	30	13	0	3	4	114
2006	0	0	0	5	0	0	5	32	13	23	0	1	79
2007	0	0	12	0	0	0	10	11	11	5	5	7	61
Avg.	***0***	***7***	***10***	***7***	***3***	***13***	***59***	***43***	***9***	***23***	***9***	***5***	***186***

Table E-6. Estimated Entrainment, Shokihaze Goby, Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	20	20
2001	0	0	-	0	5	12	6	34	83	15	4	25	184
2002	-	6	17	29	20	8	0	32	38	24	26	1	200
2003	0	23	13	7	0	8	0	0	28	16	76	8	178
2004	0	6	4	3	4	6	6	0	13	0	8	3	54
2005	0	15	5	25	40	6	91	84	49	10	17	11	352
2006	0	23	16	36	10	47	75	52	75	46	13	7	399
2007	0	19	67	27	63	56	28	32	198	185	75	8	758
Avg.	***0***	***11***	***17***	***16***	***18***	***18***	***26***	***29***	***60***	***37***	***27***	***10***	***268***

Table E-7. Estimated Entrainment, American Shad (Sensitive Species), Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	11	0	4	0	16
2001	0	0	-	0	0	0	138	0	0	0	0	0	138
2002	-	0	0	0	0	0	0	0	10	0	0	0	10
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	4	0	0	0	0	5	0	0	0	9
2005	0	0	0	0	0	0	0	3	0	5	0	0	8
2006	0	0	0	0	0	6	0	0	0	0	0	2	8
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***0***	***0***	***0***	***0***	***0***	***1***	***17***	***0***	***3***	***1***	***1***	***0***	***23***

Table E-8. Estimated Entrainment, Pacific Staghorn Sculpin, Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	5	15	16	9	38	18	8	55	9	0	173
2001	0	0	-	90	17	4	7	41	61	30	24	3	278
2002	-	4	0	0	18	36	0	129	33	78	36	6	340
2003	0	0	0	4	22	12	0	13	54	40	4	17	166
2004	0	3	0	14	12	6	18	54	22	27	8	0	164
2005	0	0	0	0	52	0	11	0	47	18	12	3	144
2006	0	0	0	0	0	4	0	0	28	14	20	0	65
2007	0	0	0	3	0	5	33	64	105	46	40	2	298
Avg.	***0***	***1***	***1***	***16***	***17***	***9***	***14***	***40***	***45***	***38***	***19***	***4***	***203***

Table E-9. Estimated Entrainment, Starry Flounder, Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	2	6	3	0	0	0	5	0	12	7	5	40
2001	0	0	-	0	0	0	0	4	0	4	11	3	22
2002	-	0	0	0	0	5	7	40	6	0	3	5	66
2003	0	15	22	0	57	10	13	16	14	5	5	3	160
2004	0	7	3	3	27	46	66	37	5	5	0	2	202
2005	0	12	3	15	0	32	11	0	8	23	6	3	113
2006	0	10	6	0	3	4	19	9	8	6	0	0	65
2007	0	22	22	3	11	39	10	11	11	0	14	3	144
Avg.	***0***	***9***	***9***	***3***	***12***	***17***	***16***	***15***	***7***	***7***	***6***	***3***	***102***

Table E-10. Estimated Entrainment, Chinook Salmon (Sensitive Species), Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	-	0	5	0	0	0	0	0	0	0	5
2002	-	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	4	0	0	0	0	0	0	0	0	0	4
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***0***	***0***	***1***	***0***	***1***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***1***

Table E-11. Estimated Entrainment, Plainfin Midshipman, Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	6	0	0	0	0	0	6
2001	0	0	-	0	0	0	87	40	31	0	0	0	158
2002	-	0	0	0	0	8	27	6	8	0	0	0	48
2003	0	0	0	0	0	0	0	92	0	0	0	0	92
2004	0	0	0	0	0	0	0	0	4	0	0	0	4
2005	0	0	0	0	0	0	0	0	10	5	0	0	15
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	14	0	5	0	0	18
Avg.	***0***	***0***	***0***	***0***	***0***	***1***	***15***	***19***	***7***	***1***	***0***	***0***	***43***

Table E-12. Estimated Entrainment, Pacific Herring, Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	-	0	0	0	0	0	0	0	0	0	0
2002	-	0	0	5	9	5	0	0	0	0	0	0	18
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***0***	***0***	***0***	***1***	***1***	***1***	***0***	***0***	***0***	***0***	***0***	***0***	***2***

Table E-13. Estimated Entrainment, Threadfin Shad, Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	-	0	0	0	0	0	0	0	0	0	0
2002	-	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	12	0	2	14
2007	0	0	0	0	0	0	0	0	0	4	0	6	10
Avg.	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***2***	***0***	***1***	***3***

Table E-14. Estimated Entrainment, Delta Smelt (Sensitive Species), Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	11	0	0	0	0	0	0	0	0	2	0	13
2001	0	0	-	0	0	0	4	8	0	0	0	0	13
2002	-	0	0	0	0	14	0	0	0	0	3	0	17
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	3	0	0	0	0	0	0	0	0	3
2005	0	0	0	0	0	0	0	2	0	0	0	1	3
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***0***	***1***	***0***	***0***	***0***	***2***	***1***	***1***	***0***	***0***	***1***	***0***	***6***

Table E-15. Estimated Entrainment, Splittail (Sensitive Species), Middle Ground

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	6	0	0	0	0	0	1	7
2001	0	2		0	0	3	0	0	0	3	0	1	9
2002		9	0	0	0	0	0	0	0	0	0	0	9
2003	0	0	0	0	0	0	0	0	5	0	0	0	5
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	2	2
2006	0	0	0	0	3	6	19	5	0	0	0	0	33
2007	0	5	3	0	4	0	0	0	0	0	0	1	13
Avg.	***0***	***2***	***0***	***0***	***1***	***2***	***2***	***1***	***1***	***0***	***0***	***1***	***10***

Appendix F

Suisun Marsh Regional Abundance Indices for All Fish Taxa; Entrainment Estimates for Most Abundant and Sensitive Species in Suisun Marsh Mining Leases

Table F-1. Total Abundance Indices for All Fish Taxa Collected by IEP in Suisun Marsh

Common Name	Scientific Name	Abundance, Demersal Habitat	Abundance, Pelagic Zone	Total Abundance	% Total
American Shad	*Alosa sapidissima*	4,323	171,029	175,352	24.4%
Striped Bass	*Morone saxatilis*	78,212	50,684	128,896	18.0%
Threadfin Shad	*Dorosoma petenense*	235	94,068	94,304	13.1%
Shokihaze Goby	*Tridentiger barbatus*	70,957	0	70,957	9.9%
Longfin Smelt	*Spirinchus thaleichthys*	12,351	46,066	58,417	8.1%
Yellowfin Goby	*Acanthogobius flavimanus*	26,133	19,994	46,127	6.4%
Delta Smelt	*Hypomesus transpacificus*	2,368	31,159	33,527	4.7%
White Catfish	*Ameiurus catus*	25,582	2,045	27,627	3.8%
Chinook Salmon	*Oncorhynchus tshawytscha*	332	22,194	22,526	3.1%
Channel Catfish	*Ictalurus punctatus*	19,717	0	19,717	2.7%
Starry Flounder	*Platichthys stellatus*	7,318	1,719	9,037	1.3%
Splittail	*Pogonichthys macrolepidotus*	2,381	3,186	5,566	0.8%
Shimofuri Goby	*Tridentiger bifasciatus*	4,208	177	4,384	0.6%
Tule Perch	*Hysterocarpus traskii*	4,047	245	4,293	0.6%
Pacific Lamprey	*Lampetra tridentata*	3,017	0	3,017	0.4%
Pacific Staghorn Sculpin	*Leptocottus armatus*	2,841	0	2,841	0.4%
River Lamprey	*Lampetra ayresii*	2,308	0	2,308	0.3%
White Sturgeon	*Acipenser transmontanus*	1,833	348	2,182	0.3%
Pacific Herring	*Clupea pallasii*	176	1,696	1,872	0.3%
Bigscale Logperch	*Percina macrolepida*	1,345	0	1,345	0.2%
Steelhead	*Oncorhynchus mykiss*	0	1,004	1,004	0.1%
Prickly Sculpin	*Cottus asper*	975	0	975	0.1%
Common Carp	*Cyprinus carpio*	0	293	293	0.0%
Threespine Stickleback	*Gasterosteus aculeatus*	225	0	225	0.0%
Plainfin Midshipman	*Porichthys notatus*	205	0	205	0.0%
Green Sturgeon	*Acipenser medirostris*	181	0	181	0.0%
Northern Anchovy	*Engraulis mordax*	0	162	162	0.0%
Mississippi Silverside	*Menidia audens*	0	127	127	0.0%
Green Sunfish	*Lepomis cyanellus*	0	125	125	0.0%
Sacramento Pikeminnow	*Ptychoceilus grandis*	81	0	81	0.0%

Table F-2. Estimated Entrainment, American Shad (Sensitive Species), Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	-	0	0	0	0	0	0	0	0	0	0
2002	-	0	0	0	0	0	0	0	0	0	1	0	1
2003	0	0	0	0	0	0	2	0	0	0	0	0	2
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***

Table F-3. Estimated Entrainment, Striped Bass, Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	2	2	1	0	0	0	5
2001	0	0	-	0	0	3	0	0	0	2	1	0	6
2002	-	2	0	3	0	0	0	1	2	2	0	0	11
2003	2	0	0	6	0	5	5	0	0	2	0	0	21
2004	0	2	0	0	0	0	0	0	0	1	0	0	2
2005	4	0	0	0	0	6	5	0	0	0	0	0	15
2006	4	0	0	0	0	2	4	0	1	1	0	0	13
2007	0	1	0	5	8	0	2	0	4	5	0	0	24
Avg.	***1***	***1***	***0***	***2***	***1***	***2***	***2***	***0***	***1***	***2***	***0***	***0***	***12***

Table F-4. Estimated Entrainment, Threadfin Shad, Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	-	0	0	0	0	0	0	0	0	0	0
2002	-	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***

Table F-5. Estimated Entrainment, Shokihaze Goby, Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	2	1	1	2	0	0	6
2001	0	0	-	2	0	4	5	12	36	4	7	0	70
2002	-	2	2	3	8	3	2	4	30	16	6	0	77
2003	10	0	14	5	2	0	8	1	11	32	3	0	87
2004	13	0	6	10	0	5	13	6	11	5	4	0	73
2005	4	1	0	3	3	5	1	3	27	46	10	0	103
2006	4	0	2	0	0	5	0	41	98	40	5	0	194
2007	65	12	4	37	47	9	1	21	41	27	2	0	267
Avg.	***14***	***2***	***4***	***7***	***7***	***4***	***4***	***11***	***32***	***22***	***5***	***0***	***110***

Table F-6. Estimated Entrainment, Longfin Smelt (Sensitive Species), Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	15	3	14	0	0	0	0	5	2	3	3	0	45
2001	20	9	-	0	0	0	1	0	0	0	0	0	31
2002	-	0	0	0	14	0	4	0	1	5	1	0	24
2003	0	4	0	6	0	0	0	0	0	0	0	0	10
2004	2	3	1	0	0	0	0	1	0	0	0	0	7
2005	22	2	2	0	0	0	0	0	0	0	0	0	26
2006	8	0	0	0	0	0	0	0	1	0	5	0	14
2007	0	1	3	0	0	0	2	0	0	0	0	0	5
Avg.	***10***	***3***	***3***	***1***	***2***	***0***	***1***	***1***	***1***	***1***	***1***	***0***	***20***

Table F-7. Estimated Entrainment, Yellowfin Goby, Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	18	1	0	0	0	24	116	23	5	17	1	0	205
2001	7	0	-	0	0	2	1	0	0	2	1	0	13
2002	-	1	0	0	0	0	1	0	0	1	0	0	3
2003	0	2	0	0	4	10	1	2	0	0	0	0	19
2004	4	1	1	5	0	4	0	1	0	0	0	0	17
2005	4	4	0	0	0	2	3	1	0	2	1	0	17
2006	6	0	0	0	0	0	0	0	0	1	0	0	7
2007	0	1	0	5	0	0	0	0	2	1	1	0	10
Avg.	***6***	***1***	***0***	***1***	***0***	***5***	***15***	***3***	***1***	***3***	***0***	***0***	***36***

Table F-8. Estimated Entrainment, Delta Smelt (Sensitive Species), Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	3	2	3	1	0	0	9
2001	0	0	-	0	0	0	0	0	0	0	0	0	0
2002	-	0	0	0	0	0	5	0	6	0	0	0	11
2003	0	0	0	0	0	0	1	1	0	0	0	0	2
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	1	2	0	0	3
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***0***	***0***	***0***	***0***	***0***	***0***	***1***	***0***	***1***	***0***	***0***	***0***	***3***

Table F-9. Estimated Entrainment, White Catfish, Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	3	0	2	3	0	0	0	5	0	0	0	0	13
2001	2	5	-	0	0	0	0	1	1	0	0	0	9
2002	-	3	1	4	0	0	0	0	0	0	0	0	8
2003	0	0	1	3	10	0	1	6	0	1	0	0	22
2004	0	0	5	0	4	0	0	0	0	0	0	0	9
2005	0	1	2	6	2	2	3	1	0	9	6	0	32
2006	18	0	4	8	26	11	1	33	4	2	1	0	109
2007	0	6	0	133	14	0	4	3	0	0	1	0	161
Avg.	***3***	***2***	***2***	***20***	***7***	***2***	***1***	***6***	***1***	***2***	***1***	***0***	***45***

Table F-10. Estimated Entrainment, Chinook Salmon (Sensitive Species), Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	-	0	0	0	0	0	0	0	0	0	0
2002	-	0	0	0	0	0	0	0	0	0	0	0	0
2003	2	0	0	0	0	0	0	0	0	0	0	0	2
2004	2	0	0	0	0	0	0	0	0	0	0	0	2
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg.	***1***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***1***

Table F-11. Estimated Entrainment, Channel Catfish, Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	6	6	0	0	0	0	0	0	0	0	0	0	12
2001	0	4	-	0	0	0	0	0	0	0	0	0	4
2002	-	0	0	0	2	0	0	0	0	0	0	0	2
2003	0	1	6	0	0	0	0	0	0	0	0	0	7
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	2	1	0	0	0	0	0	0	0	0	0	3
2006	0	1	0	0	0	0	0	6	1	0	3	0	10
2007	2	1	1	9	2	0	0	0	0	0	0	0	16
Avg.	***1***	***2***	***1***	***1***	***0***	***0***	***0***	***1***	***0***	***0***	***0***	***0***	***7***

Table F-12. Estimated Entrainment, Starry Flounder, Suisun Marsh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0	0	0	0	0	0	0	1	0	0	0	0	1
2001	0	0	-	0	0	0	0	0	0	0	0	0	0
2002	-	0	0	0	0	0	0	1	0	0	0	0	1
2003	0	0	0	0	2	3	0	0	1	0	0	0	5
2004	0	0	0	0	0	3	0	0	2	0	0	0	5
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	1	0	0	0	1
2007	0	0	0	0	2	4	6	1	3	0	0	0	17
Avg.	***0***	***0***	***0***	***0***	***1***	***1***	***1***	***0***	***1***	***0***	***0***	***0***	***4***