Moss Landing Power Plant Modernization Project 316(b) Resource Assessment

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EXECUTIVE SUMMARY

The purpose of this report is to evaluate alternative intake technologies for the possibility of cost-effectively lowering potential effects of the Moss Landing Power Plant's new combined-cycle (CC) units cooling water intake structure (CWIS). The new CWIS has been redesigned to reduce impingement effects of the existing Units 1 through 5 intake structure by lowering approach velocities, by installing modernized, angled rotating fish screens, and by removing a forebay tunnel that previous to 1996, trapped fishes and invertebrates. Entrainment effects of the existing CWIS will be significantly and directly reduced by the new units' 34 percent reduction in intake cooling water flow capacity. This reduction combined with the results of the 1999-2000 entrainment field sampling leads to a projection of low entrainment impacts. An unidentified species group of gobies accounts for 53 percent of all the larval fish that will be entrained by the new CWIS. Our analysis of CWIS effects on this fish is complete. Only 7 other taxa (species and groupings of species) of fish combined with the unidentified goby make up 95 percent of all the entrained number of fish larvae. The projected fractional losses of these species to the new CWIS and combined MLPP entrainment are low due to their source water abundance. The CWIS withdraws water from a source of inherently low species diversity.

The report contains the completed assessment of alternative intake technologies. Based on available technologies and the relatively low entrainment and impingement impacts projected for the new CWIS, the redesigned CWIS represents best available technology for the site. The new traveling screens will lower screen approach velocities and operate to more consistently remove debris, reducing impingement rates that are caused by entanglement. Remaining low potential effects or other uncertainties associated with projected CWIS effects will be addressed as necessary by appropriate measures now being discussed with regulatory and resource agency representatives. Duke has proposed a number of environmental enhancement measures to address these uncertainties.

The field studies and data analyses for the proposed modernization project followed the 316(b) Study Plan developed in coordination with the Technical Working Group established under the auspices of the Regional Water Quality Control Board. Findings of the completed 316(b) Demonstration resource assessment are presented graphically in the report, using the results of our 1999-2000 field studies. From these site surveys of weekly daytime and nighttime entrainment, and monthly source water larval fish concentrations, we have found that:

- Only eight taxa of larval fishes made up 95 percent of entrained larvae. The intake location is in an area that has naturally low diversity, typical of bays and sloughs, unlike the myriad of species found in Monterey Bay's marine habitats,

- Gobies (Family Gobiidae) comprised the overwhelming majority of this 95 percent,
- Three species of fish (Pacific herring, white croaker, and Pacific staghorn sculpin), having some commercial or recreational value, individually represented 5 percent of the eight taxa or species,
- The proportional entrainment estimates were relatively low for all species analyzed; below standard fishery management practices for sustainable harvests of a total stock especially when referenced to total populations,
- This year's entrained larvae are essentially the same composition, abundance, and distribution of last year's taxa collected at the beginning of our 12-month entrainment study, and
- Our results are generally similar to the previous MLPP 316(b) Demonstration's finding of low potential impact and best available intake technology.

Cancer spp. megalops concentrations collected from the same surveys of weekly daytime and nighttime entrainment, and monthly source water have shown that:

- Six species of cancer crab megalops and unidentified cancer megalops were collected in entrainment surveys at the new CC units intake,
- Four of these crab species (dungeness, brown rock, red rock, and yellow rock) have commercial importance,
- The most abundant cancer crab (hairy rock crab) collected has no commercial value,
- The proportional entrainment estimates were low for all species that could be analyzed. However, the estimates were typically based on a single survey PE value, and
- The number of adult crabs that might have resulted from the entrained megalops was low based on Fecundity Hindcast (*FH*) model results.

A summary of the estimated entrainment effects from March 1999 through February 2000 of the new combined-cycle units for the most abundantly collected fishes and cancer crabs is presented below. These values are based on analyses using the Empirical Transport Model (*ETM*), and the Fecundity Hindcast (*FH*), and Adult Equivalent Loss (*AEL*) models.

	Total Entrainment	***FH***	***AEL***	***ETM*$^{(a)}$**	***ETM*$^{(b)}$**
Unidentified gobies	2.7×10^8	300,000	*	0.026	0.107
Bay goby	1.5×10^8	*	1,045,588	0.039	0.21
Blackeye goby	1.6×10^7	1,825	16,636	0.043	0.075
Longjaw mudsucker	8.0×10^6	497	10,247	0.052	0.089
Hypsoblennius spp.	1.7×10^7	9,086	*	0.111	0.182
Pacific herring	4.4×10^6	235	243	0.129	0.134
White croaker	8.6×10^6	270	*	0.016	0.129
Pacific staghorn sculpin	*	*	*	0.036	0.118

	Total Entrainment	***FH***	***ETM*$^{(a)}$**	***ETM*$^{(b)}$**
Hairy rock crab	1.7×10^6	1,039	0.018	0.17
Yellow rock crab	0.5×10^6	131	*	*
Brown rock crab	0.8×10^6	209	*	*
Dungeness crab	0.3×10^6	167	*	*
Red rock crab	0.2×10^6	60	0.041	0.041
Slender rock crab	1.7×10^7	239	0.025	0.079

*Unavailable information or value that could not be computed.

(a) ETM values calculated using source water volumes 275, 21, and 2.2 $m^3 \times 10^6$.

(b) ETM values calculated using source water volumes 21, 21, and 2.2 $m^3 \times 10^6$.

Impingement studies reported in the previous 316(b) Demonstration showed that:

- The three most abundantly impinged fishes (northern anchovy, shiner perch, and topsmelt) were impinged at higher rates at the Units 1 through 5 intake than at the Units 6 and 7 intake,
- The majority of *Cancer* spp. crabs and *Crangon* spp. shrimps were impinged at higher rates at the Units 1 through 5 intake than at the Units 6 and 7 intake, and
- No declines in the populations of the above listed species were found attributable to impingement.

In addition to the above findings, modifications made to the Units 1 through 5 intake structure (shortening the intake conduit, lower approach velocities, and inclined traveling screens) will reduce previous impingement rates. Alternative intake technologies were evaluated for use in the improved CWIS based on their:

- Proven availability,
- Potential to reduce CWIS biological effects and minimize population-level impacts,
- Site feasibility, and
- Cost-effectiveness performance.

A stepwise evaluation process of these factors was employed to first determine a set of intake technologies that are available and proven for application at the CC site. A second stage analysis of the available and proven technologies was performed to evaluate the potential effectiveness of each alternative technology to reduce biological effects of the CWIS. The feasibility of intake technologies meeting both stage one and stage two evaluation criteria were analyzed and discussed in the report's preliminary conclusions on best technology available (BTA) for the modernization project's CWIS. The combined-cycle project CWIS is designed to correct the entrapment effect of the existing CWIS by removing the 350-foot shoreline tunnel to the traveling screens. This modification, in addition to reducing the new facility's flow capacity, will significantly reduce CC-CWIS impingement and entrainment effects and minimize the potential for impacts on source water populations of fish and invertebrates.

The new power plant's 34 percent reduction in intake flow capacity from flows in the 1983 316(b) demonstration studies of impingement and entrainment effects make it a relatively straightforward exercise to project a reduction in effects with the CC-CWIS. In addition to this significant reduction in entrainment and impingement effects, our report examines various proven and available intake technologies and their cost-effectiveness to reduce even further a very low potential for intake effects. An assessment of additional technology-based reductions in CWIS effects requires a site-specific understanding of both existing and projected CWIS biological effects and impacts. A wide range of site-specific information is available from previous source water and CWIS studies of the existing MLPP. A long-term study began in March 1999 to validate these previous findings and conclusions and assess present cooling water entrainment and biological conditions in the MLPP source water. This study was completed in February 2000.

The design and operation of the cooling water system for the new combined-cycle units are described along with a discussion of the physical and biological characteristics of the source water. The findings of our long-term study that began in March 1999 were used in the biological evaluation of alternative CC-CWIS technologies. Separate sections of the report present information on CWIS entrainment and impingement at the power plant, followed by a preliminary assessment of CWIS effects and potential population-level impacts used in evaluating the report's list of alternative technologies.

The proposed new combined-cycle units CWIS design represents the best technology available for the site. From both past MLPP CWIS and source water studies and our present study findings, potential entrainment and impingement effects are relatively minor, and therefore any intake technology not already proposed would represent minor potential for further reductions. However the new combined-cycle CWIS's lower intake flows, improved traveling screen and elimination of forebay entrapment tunnels are proven and available alternative intake technologies that meet site engineering feasibility, and cost-effectiveness criteria. The implementation and benefit from these improved technologies are included in our assessment of best intake technology available for the new combined-cycle CWIS.

1.0 INTRODUCTION

The following report presents the preliminary results of a cooling water intake technology evaluation required under Section 316(b) of the Federal Clean Water Act (CWA). A 316(b) demonstration program is currently being conducted at Duke Energy's Moss Landing Power Plant (MLPP) to evaluate power plant cooling water intake system effects and the proposed new combined-cycle units intake technology relative to Best Technology Available (BTA).[1] Duke Energy is planning to modernize the power plant and has submitted its Application for Certification (AFC) to the California Energy Commission. Modernization project changes that are proposed for the existing intake are relatively minor facility modifications that will significantly reduce intake effects. The necessary National Pollutant Discharge Elimination System (NPDES) permitting process for this modernization project is being administered in parallel to the AFC process by the California Central Coast Regional Water Quality Control Board (RWQCB). This 316(b) report is submitted in accordance with the specifications of the RWQCB's "Requirements Letter" of July 21, 1999.

The Clean Water Act's (PL 92-500 and 95-217) Section 316(b) requires that ". . . the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact" (EPA, 1977). Because no single intake design can be considered to be the best technology available at all sites, compliance with the Act requires a site-specific analysis of intake-related organism losses and a site-specific determination of the best technology available for minimizing those losses. In this report, intake-related losses resulting from entrainment (the drawing of organisms into the cooling water system) and impingement (the retention of organisms on the intake screens) are evaluated and discussed. Intake technologies are evaluated according to operating, engineering, and biological criteria; the best technology available for minimizing entrainment and impingement losses is recommended for the cooling water intake structure of the Moss Landing Power Plant new combined-cycle units.

The first 316(b) demonstration program studies were conducted at the Moss Landing Power Plant from 1978 through mid-1980 (PG&E, 1983). This program followed the general guidance provided by the California State Water Resources Control Board (SWRCB), Environmental Protection Agency (EPA), California Department of Fish and Game (CDFG), and United States Fish and Wildlife Service (USFWS). Entrained and impinged organisms were sampled on a weekly basis to gather information on the species composition and abundance of organisms affected by the plant's cooling water system. Special studies were also conducted to examine the potential survival of entrained and impinged organisms. Data collected from numerous surveys

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[1] The RWQCB determined that the existing permitted intake represented the Best Technology Available based on the results of the previous 316(b) study (PG&E, 1983).

near the plant were used in conjunction with CDFG commercial and sportfish landing data to examine the general trends in the populations of some of the species susceptible to the effects of the cooling water systems. The information gathered from these studies was used in conjunction with engineering and operating criteria to evaluate alternative intake technologies for the plant.

The report concluded that there was no evidence that local populations were adversely affected by the operation of the MLPP. Furthermore, it was demonstrated that the feasible alternative intake technologies examined would not have substantially reduced biological losses at the plant on a cost-effective basis.

The 316(b) demonstration was reviewed by several agencies including the SWRCB, RWQCB, CDFG, EPA, and USFWS. Questions raised by the agencies during the review process were answered in supplemental responses to the 316(b) Demonstration Report. The conclusion of these agencies was that no alternative intake technologies or changes to the operations of the power plant were required based on the information presented in the demonstration and information provided to the agencies during the review process. The modernization project has no plans to change the approved Units 6 and 7 intake facilities.

1.1 Development of the 316(b) Study Plans

In 1998 Duke Energy announced their plan to modernize the Moss Landing Power Plant. The RWQCB was contacted and a series of meetings were held to discuss the renewal of the plant's NPDES permit. The RWQCB assembled a team of experts to assist the Board's staff in their review of the design and implementation of the 316(b) studies. This team, the Technical Working Group (TWG), met periodically to discuss topics relevant to ongoing efforts at MLPP including the design of the 316(b) study plan. The study plan entitled *Final Moss Landing Power Plant Modernization Project Cooling Water Intake and Discharge Study Plans*, (Tenera, Inc., 1999) was submitted to the RWQCB on November 18, 1999.

The design of the 316(b) field study program was based, in part, on information collected during previous studies of the potential effect on the aquatic communities of Moss Landing Harbor, Elkhorn Slough, and Monterey Bay resulting from operation of the Moss Landing Power Plant's cooling water systems. The three most significant studies were those conducted by PG&E relating to the effect of the cooling water discharges on the beneficial uses of the receiving waters at the MLPP (PG&E, 1973), the MLPP Units 1 through 5 316(a) demonstration program (PG&E, 1978), and the MLPP Cooling Water Intake Structures 316(b) Demonstration (PG&E, 1983). The study plan was developed using information collected in these and other studies of the area in combination with state and federal 316(b) guidelines and was also based on input from the TWG.

Three modeling approaches for use in assessing entrainment and impingement losses were presented to the TWG. These approaches are adult equivalent loss (*AEL*), fecundity hindcasting (*FH*), and empirical transport model (*ETM*). These models were described in a draft report entitled, *Moss Landing Power Plant Modernization Project Cooling Water System Intake Effects, Estimating Taxa Losses Caused by Entrainment and Impingement*, that was submitted to the TWG September 1, 1999. The report was reviewed by the TWG and their comments were addressed. The report was incorporated into the *Final Moss Landing Power Plant Modernization Project Cooling Water Intake and Discharge Study Plans* (Tenera, Inc., 1999).

1.2 Overview of the 316(b) Program

The basic objective of the 316(b) program is to provide a sufficient basis for regulatory agencies to determine whether the new combined-cycle cooling water intake structure (formerly the Units 1 through 5 intake structure) reflects the best technology available for minimizing adverse environmental impacts. To accomplish this objective, a field study program was designed and conducted to determine the extent of entrainment effects at the Moss Landing Power Plant. The numbers of aquatic organisms entrained are estimated from plankton samples collected in front of the intake structures. Samples collected in Monterey Bay, Moss Landing Harbor, and Elkhorn Slough provided estimates of the source water populations that may be affected by entrainment.

Consistent with the final study plan, impingement studies were not conducted. The intake structure for the new combined-cycle units will be modified as part of the modernization project. Impingement rates at the modernized combined-cycle units intake are expected to decrease from those reported in PG&E (1983) as a direct result of these changes.

1.2.1 Target Organisms Selected for Study

The TWG selected the following aquatic organism groups to be the focus of the 316(b) entrainment study at the Moss Landing Power Plant:

- Fishes (all life stages)
- *Cancer* spp. (megalopal life stage)
- European green crabs *Carcinus maenas* (megalopal life stage).

Fishes and *Cancer* spp. crabs were selected because of their role in the ecosystem and because some of them have commercial or recreational value. European green crabs, an introduced invasive species, were selected because of concerns regarding their presence in the vicinity of the MLPP.

This report presents the results of the model approaches applied to the concentrations of the most abundant fish taxa and all cancer crabs collected in the entrainment samples. Concentrations of all larval fish taxa are expressed as the number per 1,000 cubic meters (#/1,000 m^3).

For this report, we further narrowed the focus of the assessment of entrainment effects to the most abundant taxa of larval fishes and all cancer crabs. Based on the results of entrainment sampling to date, the eight most abundant entrained larval species or taxa groups of fishes were chosen for assessment in this report. They are unidentified gobies, bay goby, blackeye goby, Pacific staghorn sculpin, white croaker, blennies, longjaw mudsucker, and Pacific herring. All targeted cancer crab species were assessed.

1.3 Organization of the Report

This 316(b) demonstration is a summary and analysis of the data collected and processed from March 1999 through February 2000. All data from field collections are preliminary because laboratory processing quality control checks have not all been completed. This report includes Sections 1 through 8. The design and operation of the existing Units 6 and 7 intake structure as well as the proposed modernization project's intake structure are described in Section 2. The experimental design and study and assessment methods for the entrainment and source water studies are presented in Section 3. Section 4 presents the life histories, entrainment and source water survey results, and data comparisons with the previous entrainment study for the eight fish taxa listed above and the targeted crab species. Impingement data that were collected during the 1979 – 1980 316(b) study have been reanalyzed to estimate the rate of impingement and are presented in Section 5. Entrainment and impingement effects are evaluated in Section 6. The best technology available (BTA) for the modernized intake system is assessed in Section 7. Literature cited in the report is listed in Section 8.

2.0 DESCRIPTION OF THE MOSS LANDING POWER PLANT AND CHARACTERISTICS OF THE SOURCE WATER BODY

This section describes the Moss Landing Power Plant (MLPP) and its aquatic environmental setting, focusing on the various features of the existing and proposed power plant design and operations related to the facility's aquatic environment. Section 2.1 describes the plant and its existing and proposed cooling water systems. Section 2.2 briefly characterizes the aquatic environment in the vicinity of the MLPP. An analysis of whether the modernized system represents the best technology available to minimize potentially adverse cooling water intake effects is given in Section 7.

2.1 The Plant and its Cooling Systems

The Moss Landing Power Plant is located on the eastern shoreline of Moss Landing Harbor. This medium sized harbor, which provides dock space for approximately 600 commercial and recreational vessels, is located about 110 miles (177 km) south of San Francisco. Moss Landing Harbor is located roughly midway between Santa Cruz and Monterey, California and is open to Monterey Bay (Figure 2-1). The plant is located in a relatively undeveloped area that includes industrial facilities, agricultural lands, sparse residences, recreational beaches, and tidal wetlands. The MLPP has two separate intake structures in Moss Landing Harbor for withdrawal of cooling water that is necessary to remove excess heat from the power generation process. One intake previously serviced the now retired Units 1 through 5 and is currently unused and a second intake structure services the presently operating Units 6 and 7. Cooling water from Units 6 and 7 is discharged into Monterey Bay through two (one/unit) subsurface conduits. Historically, cooling water from Units 1 through 5 discharged into Elkhorn Slough. The design (historic), actual (current), and projected specifications of the new combined-cycle units cooling water intake structure (CWIS) are summarized in Table 2-1.

The Moss Landing Power Plant (MLPP) currently produces up to about 1,500 MW from two steam boilers (Units 6 and 7). In addition, the MLPP site includes retired Units 1 through 5.

Duke Energy proposes to replace the 1950s technology of Units 1 through 5 with two 530-MW high efficiency combined-cycle (CC) units. Each combined-cycle unit will consist of two advanced class combustion turbine generators, two heat recovery steam generators, and a single steam turbine generator. Only the new steam turbine generators will require a significant amount of ocean cooling water. About two-thirds of the total new power output will be produced by the combustion turbine generators, which require no ocean cooling water.

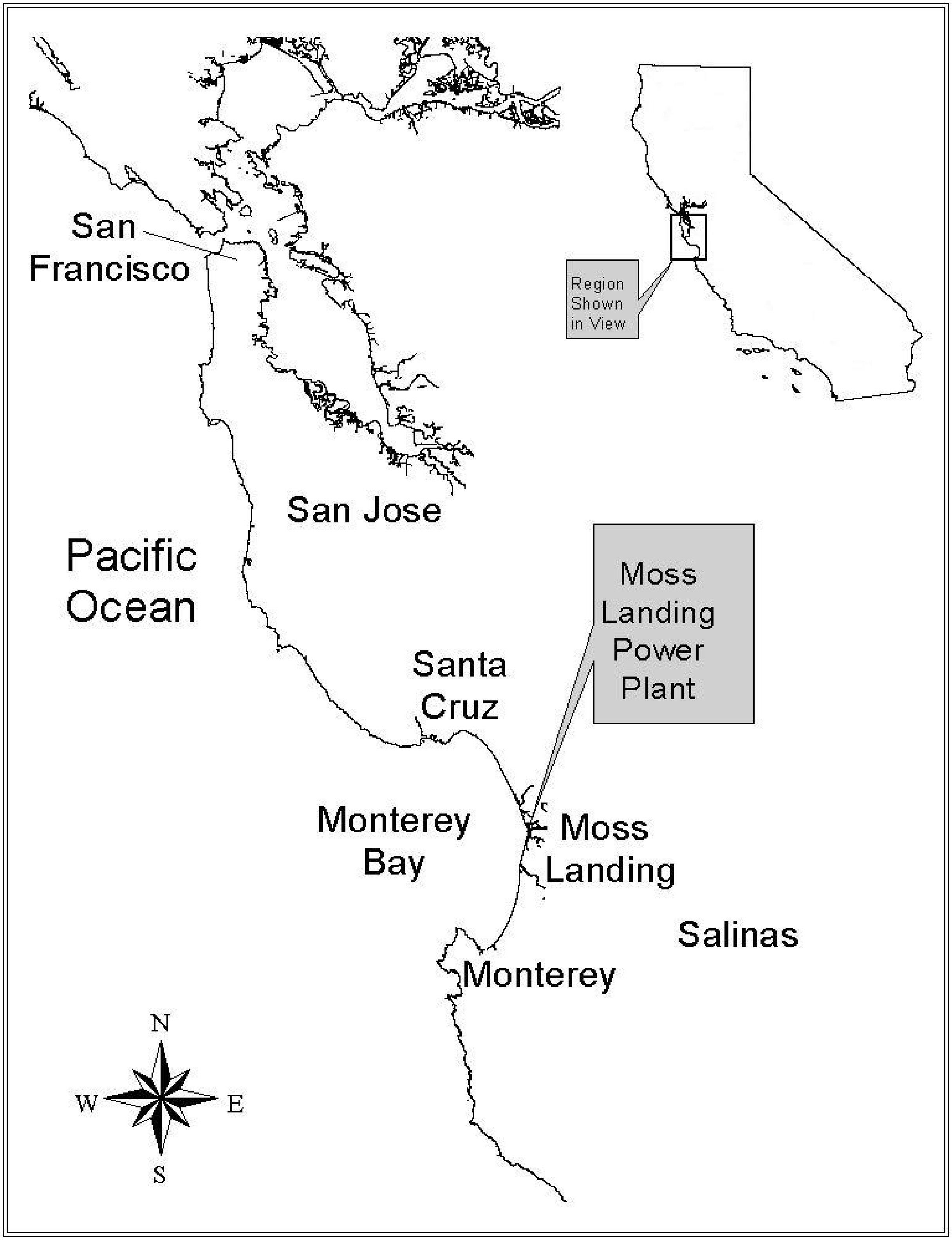


Figure 2-1. The location of the Moss Landing Power Plant.

Table 2-1. Historic and Projected Specifications of the Cooling Water Intake Structures at MLPP, Units 1 through 5 and the New Combined-cycle Units.

Note: Units 1 through 5 were retired in 1995. TBD = to be determined.

	Historic (Design)		**Projected(1) (AFC Design as Revised)**
Intake Flow Rate	381,000 (gpm) 1,441 (m^3/min)		250,000 (gpm) 946 (m^3/min)
Units 1–3 and Units 4 and 5 Intake	**Units 1–5**		**New Combined-cycle Units**
Bar Racks			
Number	6		6
Location	Shoreline		Shoreline
Spacing OC	4 (in.) 10.2 (cm)		4 (in.) 10.2 (cm)
Bar size	3 x 3 / 8 (in.) 7.6 x 0.9 (cm)		TBD
Intake Conduits to Screenhouse			
Number	2 (a)		6
Size	9.3 x 10.6 (ft) 2.8 x 3.2 (m)		10 ft x 27ft deep
Length	350 (ft) 107 (m)		~ 10 (ft) ~ 3 (m)
Traveling Screens	Vertical		Inclined
Location	Onshore		Shoreline
Number	6		6
Manufacturer	Link Belt		TBD
Mesh size	3/8 (in.) 0.9 (cm)		5/16 (in.) 0.8 (cm)
Pumps per unit	**Units 1-3**	**Units 4-5**	
Location	Onshore	Onshore	Onshore
Number	2	2	3 (6,total)
Manufacturer	Foster Wheeler	Foster Wheeler	TBD
Type	Mixed flow single-stage vertical	Mixed flow single-stage vertical	TBD
Capacity (each pump)	104.5 (cfs) 2.96 (m^3/sec) 46,900 (gpm)	55.5 (cfs) 1.57 (m^3/sec) 24,900 (gpm)	42,000 gpm
Water velocities at maximum capacity, mean low, low water			
Approach to bar racks	0.7 (fps) 21.34 (cm/sec)	(2)	0.5 (fps) 15 (cm/sec)
Through bar racks	0.9 (fps) 27.43 (cm/sec)	(2)	0.6 (fps) 18 (cm/sec)
Approach to screens	1.0 (fps) 30.48 (cm/sec)	(2)	0.5 (fps) 15 (cm/sec)
Through screens	2.4 (fps) 73.15 (cm/sec)	(2)	0.6 (fps) (3) 18 (cm/sec)

(1) Units 1 through 5 intake structure modified to serve the new combined-cycle plant.

(2) Information about bar racks and traveling screens applies to unit-group intakes (Units 1 through 5 share a common intake structure).

(3) Through screen velocity based on 65 percent open screen area and 55º slope from horizontal.

Therefore, the new combined-cycle units will be capable of generating about 1,060 MW while using about 250,000 gpm (946 m^3/min) of once-through ocean cooling water (at 20 °F [11.1 °C] temperature increase). By comparison, the existing Units 6 and 7 require about 600,000 gpm (2,270 m^3/min) of ocean cooling water (at 28 °F [15.5 °C] temperature increase) to generate 1,500 MW.

In addition to the new combined-cycle units, Duke Energy proposes to upgrade existing Units 6 and 7 through replacement of the steam turbine high-pressure rotor, which will result in an additional 15 MW per unit of generation capacity. These two actions combined yield an additional 1,090 MW (i.e., 1,060 MW + 30 MW) and constitute the Modernization Project.

2.1.1 Plant Cooling Water System Description and Operation

2.1.1.1 Units 1 through 5 Cooling Water System: Previous Operation and Proposed Modifications

Since 1995, Units 1 through 5 have been removed from service and use of that cooling water system has been discontinued. The existing intake system for Units 1 through 5, which will be renovated for the Project, is shown schematically in Figure 2-2. The common cooling water intake structure for Units 1 through 5 is located on the eastern shore of Moss Landing Harbor. Seawater drawn through bar racks at the entrance to the intake structure previously passed under the coast highway through approximately 350 feet of tunnel to reach the traveling screens and circulating water pumps located in a pumpwell structure inside the plant. Each of the five units had two circulating water pumps that historically pumped cooling water to the condensers through two conduits, one serving each condenser half.

Figure 2-2 shows the major features of the existing intake structure. Bar racks, spaced 4 inches on center, and located about 350 feet in front of the six vertical traveling screens, prevented the entry of large objects into the cooling water system. The vertical traveling screens, with a mesh size of 3/8 inch, retained smaller objects. Materials retained by the screens were removed during screen rotation and washing. Screen rotation and washing were initiated automatically at approximately 24-hour intervals, or when the across-screen hydraulic pressure differential exceeded a predetermined maximum.

The project proposes to modify the existing intake structure previously used for Units 1through 5 to serve the new CC units. The traveling screens for the modernized Units 1 through 5 intake will be located as close as practical to the shoreline, thus reducing the length of the intake tunnel upstream of the screens from 350 feet to approximately 10 feet (see Figure 2-3). The new traveling screens for the CC Units will be inclined at approximately 55 degrees from horizontal (Figure 2-4), and will be made of continuously woven 18 x 18 x 14 wire mesh with 3-inch tines

Figure 2-2. Existing MLPP Units 1 through 5 cooling water intake structure.

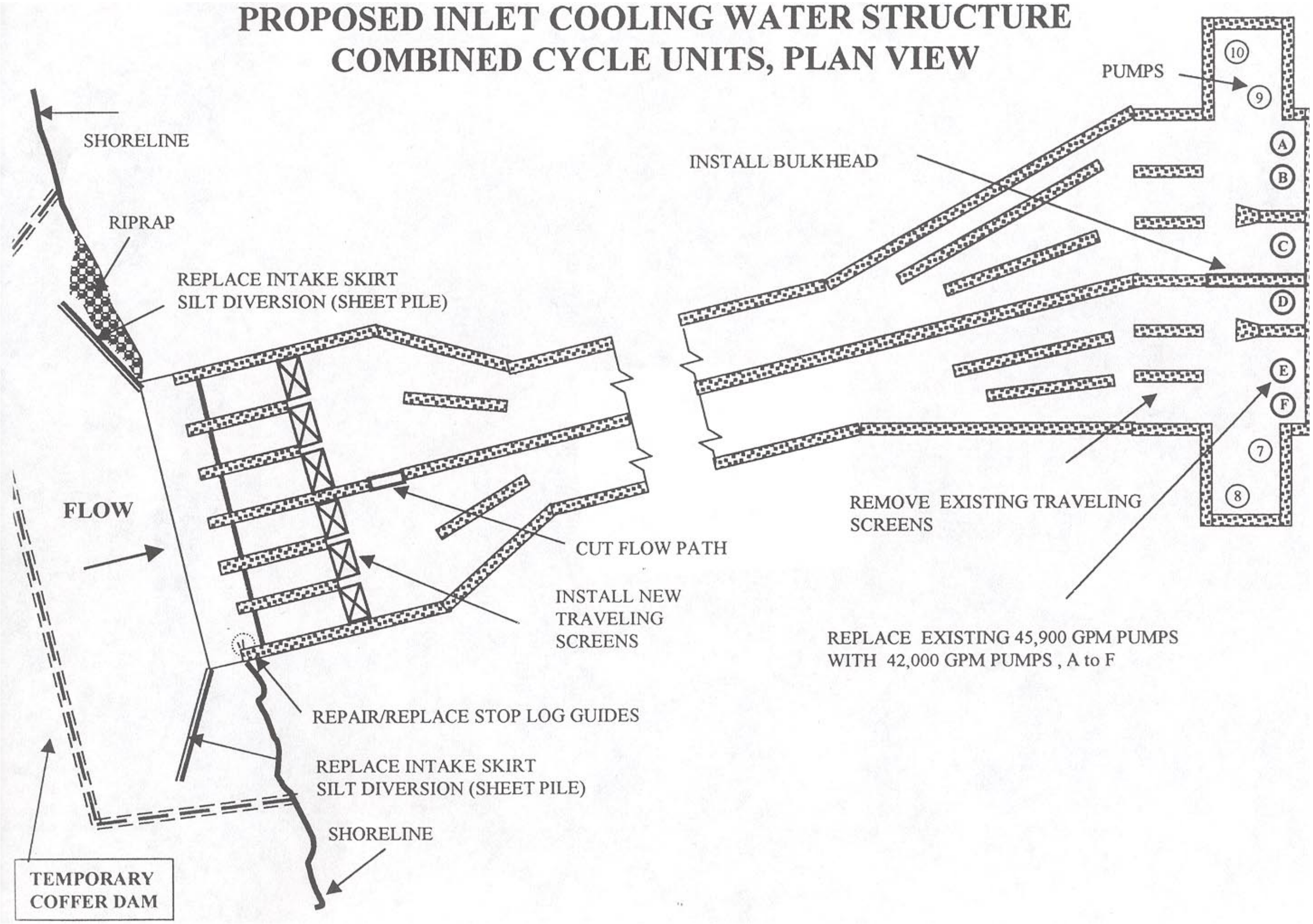


Figure 2-3. Proposed modernized MLPP combined-cycle cooling water intake structure.

Figure 2-4. Sectional view of the MLPP new combined-cycle units intake structure's traveling screens.

to assist with removal of accumulated eelgrass *Zostera marina* during the fall season. The wire mesh will have the equivalent of a 5/16 inch opening and will have the maximum width possible to fit between the existing stop log guides. The lower flow rate approaching the screens and higher cross-sectional area of the screen has the net effect of reducing the approach velocity at maximum capacity and mean low, low water, from the historic value of about 0.7 fps to approximately 0.5 fps for the new CC units.

In addition, the internal walls of the intake structure will be modified to allow periodic heat treatment for removal of macroinvertebrates over the entire length of the intake system, from the shoreline screens to the condensers in the new CC units. Previously, it was possible to heat treat only the portion of the Units 1 through 5 intake system from the inland screenwell to the condensers, allowing organisms to more readily colonize the 350 feet of untreated intake tunnels upstream of the screens. Predation by these unremoved organisms was thought to significantly reduce the entrainment survival rate in the old Units 1 through 5 system. The heat treatment procedure is described in the following section.

2.1.1.2 Units 6 and 7 Cooling Water System: Design and Operational Procedures

The intake for the once-through seawater cooling system currently serving Units 6 and 7 is shown schematically in Figure 2-5. The intake structure, located on the shore 700 feet south of the Units 1 through 5 intake structure, consists of bar racks, traveling screens, and circulating water pumps. The cooling water flow of Unit 6 is separate from that of Unit 7. Separate subsurface conduits carry the discharge from each unit to a submerged offshore discharge structure located in Monterey Bay 2,400 feet from the plant, about 550 to 600 feet offshore, shown in Figure 2-6.

Figure 2-5 shows the major features of the intake structure. Bar racks, spaced 4 inches on center, are located about 15 feet in front of the eight vertical traveling screens. The traveling screens are 3/8-inch mesh. Material retained by the screens is removed during screen rotation and washing. Washing is initiated automatically either by a timer, at approximately 24-hour intervals under normal operating conditions, or when the hydraulic pressure differential across the screen exceeds a predetermined maximum. During screen washing, spray nozzles wash the collected material into a surrounding sluiceway which empties into a screenwash wet well. The screenwash discharge, less the impinged materials, is returned to Monterey Bay by large-diameter screen refuse pumps that empty into the discharge conduit of Unit 6. The impinged material that separates in the wet well is periodically removed by a local refuse collection contractor and trucked to a sanitary landfill for disposal.

Figure 2-5. MLPP Units 6 and 7 cooling water intake structure.

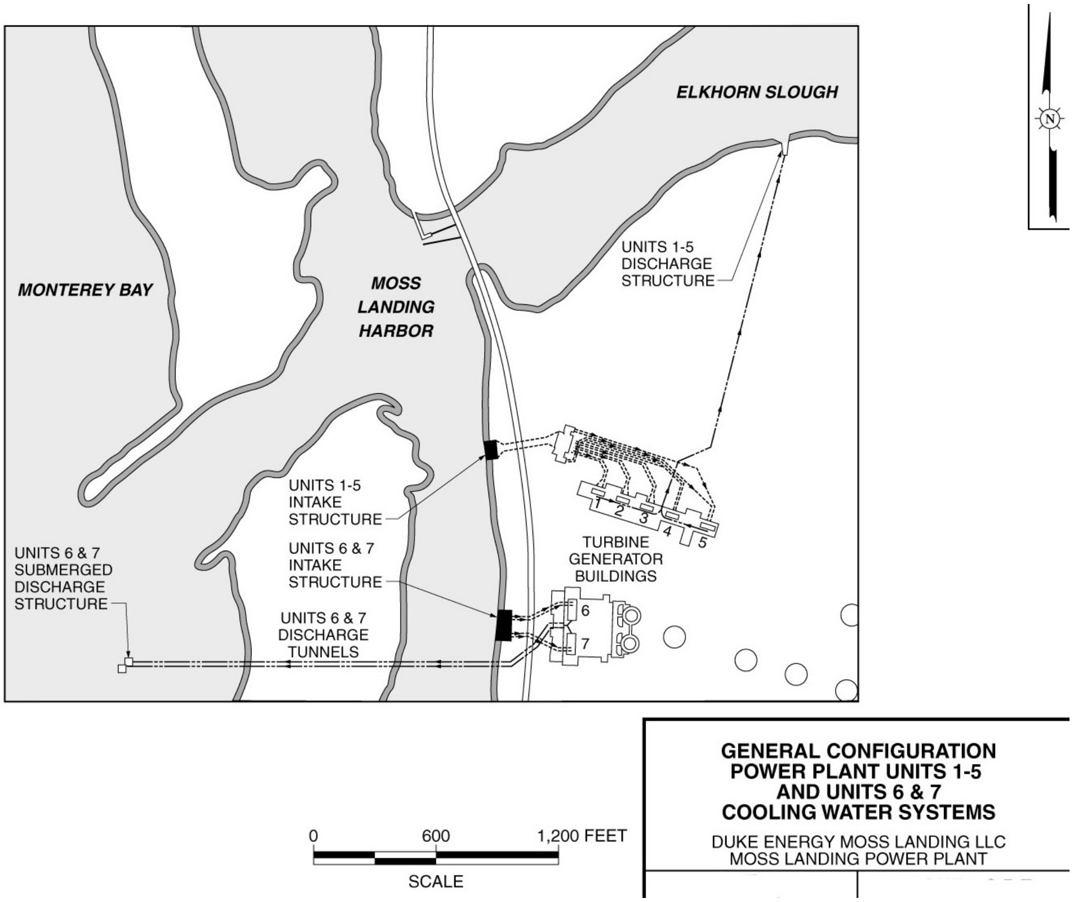


Figure 2-6. Location of the MLPP Units 6 and 7 discharge structure.

The new CC units cooling water discharge will combine with the existing Units 6 and 7 cooling water discharge lines on-shore, inside the plant. There are no design changes to the existing Units 6 and 7 outfall structures located as shown in Figure 2-6. The tops of the discharge pipes are located approximately 20 feet off the bottom and 20 feet below the surface. The net effect of adding the new CC units discharge cooling water to the Units 6 and 7 discharge flow in the existing 12 foot diameter lines is to increase the velocity in the pipe from approximately 5.9 feet per second to approximately 8.6 feet per second at maximum flow. It should be noted that in the future, at energy demands at the MLPP of less than about 1,000 MW, the velocity in each pipe will be reduced to approximately 2.5 feet per second as only the two new more efficient combined-cycle plants will be operating.

A chemical feed system consisting of a storage tank with injection pumps is used intermittently, as necessary, to supply sodium hypochlorite (12 to 14 percent bleach solution), a biofouling inhibitor, into the incoming cooling water supply lines immediately after the Units 6 and 7 intake screens and before the condensers, to reduce biofouling of the condenser. Residual chlorine will not exceed the permitted quantity of 200 parts per billion (ppb) at the outfall. The procedures and chemical limits are closely regulated by the Regional Water Quality Control Board (RWQCB). The new CC units will utilize a similar system, except that the hypochlorite solution injection point will be located at the condenser inlets.

Integral to the design of the circulating water system will be provisions for demusseling. Demusseling is required, from time to time, to remove flow obstructions within the circulating cooling water system. This procedure will utilize the online condensers of both units to supply heated cooling water into the cooling water supply line and intake tunnel by reversing the flow through the part of the system being treated. The amount of time necessary to demussel an inlet tunnel at treatment temperature is dependent on the water temperature, but is typically 1 hour. The total treatment cycle from beginning to end is expected to take 4 to 6 hours. The intake stop logs on the tunnel being treated are closed to prevent flow of heated water to the harbor. At the same time, the discharge line from the condenser feeding the line being treated is closed. The heated treatment water flows into the active intake tunnel when the stop logs on the treated tunnel are closed. The discharge of the unit receiving blended cold intake and recycled treatment water is restricted to force part of the flow through a crossover line to the unit being treated. The balance of the water flows through the partially closed discharge valve to the discharge tunnels. At the end of treatment, the discharge valves and intake stop logs are opened and the circulation pumps restarted. This procedure is repeated, as necessary, approximately every 4 to 6 weeks in each unit. Units 6 and 7 currently employ this procedure for demusseling the inlet cooling water tunnels, a process which is also currently regulated by the RWQCB. Closure of the stop logs assures that heated cooling water is discharged only to the permitted discharge outfall and not to the harbor by reverse flow through the intake structure. This process is conducted solely for control of marine growth in the cooling water intake lines and is not intended to provide any backwash cleaning of the condensers.

As described above, the new CC units will also incorporate the capability for periodic heat treatment of cooling water intake lines.

2.2 Aquatic Biological Resources in the Vicinity of MLPP

The MLPP is situated at the intersection of three distinct marine geographic areas: Elkhorn Slough (tidal lagoon), Moss Landing Harbor, and Monterey Bay. Each of these areas has its own unique aquatic biological habitats. Distinct aquatic habitats present within the boundaries of Moss Landing Harbor and Elkhorn Slough include shallow open water, submerged aquatic vegetation, sand/mud/salt flats, fresh/salt/brackish marshes, rocky subtidal and intertidal. Distinct habitats present in Monterey Bay include sandy beach, rocky intertidal and subtidal and open water areas.

2.2.1 Elkhorn Slough/Moss Landing Harbor

Elkhorn Slough is a narrow, shallow water embayment that extends 6.2 miles inland from the eastern margin of Monterey Bay. As it extends inland, it gradually narrows and decreases in depth. Tidal mud flats and pickleweed (*Salicornia* spp.) marsh extend the length of the slough. The drainage basin for Elkhorn Slough is small, only 226 square miles in area. The land near the slough is used primarily for agriculture. Shallow open water and lagoon habitats comprise the majority of aquatic habitat provided by the Elkhorn Slough and Moss Landing Harbor complex.

Several changes have occurred in the hydrology and channel geomorphology since the time of the PG&E entrainment and impingement studies in 1978-1980 (Malzone and Kvitek, 1994; Oxman, 1995; Lindquist, 1998). In the mid 1980s several dikes and levees surrounding pasture lands were reopened to tidal flow. These changes increased the surface wetlands by 48 percent and the tidal volume by 43 percent (Malzone and Kvitek, 1994). The increased volume of water exchanged with the tides has increased both the rate of erosion and the velocity of the tidal currents (Philip Williams and Associates, 1992, cited in Lindquist, 1998; Malzone and Kvitek, 1994). Recent studies of the effects of this erosion on the trophic ecology of the slough (Lindquist, 1998) and studies of the prey availability for harbor seals (Oxman, 1995) provide updated information on the species composition of adult fishes in the slough. Yoklavich et al. (Draft, 1999) discuss data collected from numerous studies (past and present) on fish assemblages found in Elkhorn Slough habitats and surrounding marine waters.

The varied marine and estuarine habitats within Elkhorn Slough provide habitat for at least 97 species of fish (representing 40 families) (Yoklavich et al., 1992; Draft, 1999). Most (76) of these species are marine species from Monterey Bay. Fish species utilizing the slough were divided by Yoklavich et al. (Draft, 1999) into several groups. Immigrant marine species typically use the slough for spawning or as a nursery ground. These species include the northern anchovy *Engraulis mordax*, Pacific herring *Clupea pallasi*, and cabezon *Scorpaenichthys marmoratus*. Numerous species of flatfish including the speckled sanddab *Citharichthys stigmaeus*, English sole *Parophrys vetulus*, sand sole *Psettichthys melanostictus*, starry flounder *Platichthys stellatus*, California halibut *Paralichthys californicus*, and several species of turbot are also considered immigrant marine species. Fish species considered permanent residents include the Pacific staghorn sculpin *Leptocottus armatus*, black surfperch *Embiotoca jacksoni*, striped mullet *Mugil cephalus*, bay pipefish *Syngnathus leptorhynchus*, and five species of gobies. Partial residents, or species that live or reproduce in the slough but migrate to the ocean during certain seasons or life stages, include the jacksmelt *Atherinopsis californiensis*, shiner *Cymatogaster aggregata* and white *Phanerodon furcatus* surfperches, leopard shark *Triakis semifasciata*, and bat ray *Myliobatis californica*. Species primarily associated with freshwater include the American *Alosa sapidissima* and threadfin *Dorosoma petenense* shad, mosquitofish *Gambusia affinis*, prickly sculpin *Cottus asper*, threespine stickleback *Gasterosteus aculeatus*, and striped bass *Morone saxatilis*. Few non-native species have been noted (yellowfin goby *Acanthogobius flavimanus*, mosquitofish, American shad, and striped bass).

In 1991, otter trawls were conducted as part of a study of fish availability as prey items for harbor seals (Oxman, 1995). Otter trawls were conducted monthly for a year (1991) in Elkhorn Slough in an effort to establish seasonal trends of fish availability and distribution. The trawls were taken at the same three stations (Bridge, Dairies, and Kirby Park) sampled by Nybakken et al. (1977) and reported by Yoklavich et al. (1992) in the main channel of the slough. Eighty-three daytime otter trawls captured 1,955 fish representing 41 species. The 29 nighttime trawls at two stations (Dairies and Bridge) resulted in 1,461 fishes representing 39 species. The lower numbers caught during the day may have been a result of fishes avoiding the net.

More then 90 percent of the fishes taken in the daytime and nighttime trawls were represented by 11 species. These fishes included shiner surfperch *Cymatogaster aggregata*, English sole *Parophrys vetulus*, staghorn sculpin *Leptocottus armatus*, California tonguefish *Symphurus articauda*, speckled sanddab *Citharichthys stigmaeus*, white surfperch *Phanerodon furcatus*, cabezon *Scorpaenichthys marmoratus*, black surfperch *Embiotoca jacksoni*, and lingcod *Ophidion elongatus*. Pipefish *Syngnathus* spp. was caught during the daytime trawls and brown rockfish *Sebastes auriculatus* was caught at night.

Oxman (1995) reported that overall there was a slight change in the 1991 diurnal fish assemblage from that reported by Yoklavich et al. (1992) during 1974-1976. These changes included a decrease in the mean number of fish per tow, species diversity decrease at the Bridge and Dairies stations, and species diversity increases at Kirby Park. Species absent from the 1991 daytime trawls that were present in 1974-1980 trawls included topsmelt *Atherinops affinis*, jacksmelt *Atherinopsis californiensis*, Pacific herring *Clupea pallasi*, threadfin shad *Dorosoma petenense*, sand sole *Psettichthys melanosticus*, blue rockfish *Sebastes mystinus*, queenfish *Seriphus politus*, and night smelt *Spirinchus starksi*. Several species were less abundant. English sole, cabezon, lingcod, and California tonguefish increased in relative abundance and density.

Oxman (1995) stated that there was a significant change in fish assemblages at the Bridge and Dairies stations since the 1974-1980 otter trawls. Several species were absent and many were caught in less abundance in the 1991 tows. English sole, lingcod, and California tonguefish increased in relative abundance and density.

Lindquist (1998) collected fishes in otter trawls to provide information on their feeding habits from four stations in Elkhorn Slough from May 1996 to May 1997. He analyzed 11 species of fish from nine families. The species were yellowfin goby *Acanthogobius flavimanus*, topsmelt *Atherinops affinis*, speckled sanddab *Citharichthys stigmaeus*, arrow goby *Clevelandia ios*, Pacific herring *Clupea pallasi*, shiner perch *Cymatogaster aggregata*, northern anchovy *Engraulis mordax*, Pacific staghorn sculpin *Leptocottus armatus*, white surfperch *Phanerodon furcatus*, English sole *Parophrys vetulus*, and California tonguefish *Symphurus atricauda*. These species accounted for 96 percent of the total abundance from the otter trawls. Of those species all but yellowfin goby and California tonguefish were dominant fishes during studies conducted in Elkhorn Slough in the 1970s (Lindquist, 1998).

Yoklavich et al. (Draft, 1999) discussed several distinct habitat types which have been sampled within the slough. Different sampling methods were used for each habitat type (otter trawl, beach seine, and channel nets). The most abundant and diverse family of fishes within the slough and surrounding coastal waters are the embiotocids. Shiner perch *C. aggregata* was the most common species found throughout the habitats studied and the Pacific staghorn sculpin *L. armatus* was the most abundant species in upper slough areas. Several large elasmobranchs are also relatively common within the slough (bat ray *M. californica*, shovelnose guitarfish *Rhinobatos productus*, gray smoothhound *Mustelus californicus*, and leopard shark *T. semifasciata*; Yoklavich et al. Draft, 1999; San Filippo, 1994).

Yoklavich (Draft, 1999) concluded that in general, fish assemblages present in Elkhorn Slough in the 1990s are characterized by decreased abundance at most sample sites as well as less diversity than in the past. Within the last twenty years a homogenization of fish assemblages appears to have occurred between the lower main channel and tidal channels. These changes have coincided with the continued erosion and scouring of smaller channels to the point that they are now similar (in habitat type) to the main channel (Malzone and Kvitek, 1994).

The most abundantly collected fishes from studies reported in Nybakken et al. (1977), Yoklavich et al. (1991), from PG&E impingement studies in 1978–80 (PG&E, 1983), and from Lindquist's work in 1996-97 generally have remained the same. Northern anchovy, shiner perch, and Pacific herring were some of the most abundantly collected fishes from all three of these studies. Topsmelt was the only species collected in high numbers in impingement samples that was not collected in the other two studies. Oxman's (1995) studies in 1991 however, showed greater differences in species composition when compared to the other studies with the exception of the presence of shiner perch. This species was collected in high numbers in the slough from all studies. Fishes that were not collected in Oxman's study but were present in high numbers in all other studies were northern anchovy and Pacific herring. Both of these missing species were again collected in high numbers in Lindquist's 1996-97 studies.

2.2.2 Monterey Bay

Monterey Bay, California's largest open-coast embayment, is formed by the extent of shoreline between Santa Cruz and Monterey and by the offshore depths of the Monterey submarine canyon. The opening of the bay is 23 miles across and 10 miles wide. Four main tributaries, the Pajaro River, Elkhorn Slough, the Salinas River, and the San Lorenzo River flow into the bay. The bay's immense supply of cold, nutrient-rich, ocean water is exchanged tidally with the Elkhorn Slough and harbor located midway along the bay shoreline at the head of the canyon.

Monterey Bay lies within the boundaries of the Monterey Bay National Marine Sanctuary (MBNMS). The MBNMS extends from 7 miles north of the Golden Gate Bridge to Cambria Rock in northern San Luis Obispo County. The sanctuary contains about 400 statute miles of coastline and extends an average of 30 miles offshore. Its total area is 5,322 square miles. The MBNMS was officially established in 1992 by the authority of the Secretary of Commerce under the 1972 Marine Protection, Research and Sanctuaries Act. The MBNMS is one of fourteen marine sanctuaries in the United States under the jurisdiction of the National Oceanic Atmospheric Association (NOAA) of the U.S. Department of Commerce.

Monterey Bay is characterized by a gently sloping shelf cut by a system of submarine canyons, the largest of which is the Monterey Submarine Canyon. The head of this canyon is located off of the entrance to Moss Landing Harbor. The depth of the canyon ranges from 60 feet to 2,800 feet. The canyon is 650 feet wide at the head and approximately 7.5 miles wide at the mouth of Monterey Bay.

Monterey Bay's sandy beach habitat extends in nearly a continuous reach of approximately 20 miles from Santa Cruz to Monterey, encompassing the Moss Landing area. Beach habitat in the area of Moss Landing is exposed to high-energy waves from the northwest. Large quantities of sand are annually transported on and off the beach shoreline by strong waves and longshore currents. The continuously changing nature of this habitat favors mobile invertebrate and fish species that adjust quickly to the depletion and accretion of sediments. Relatively few species are able to adjust to this habitat.

The marine resources of Monterey Bay support a variety of commercial fisheries (Starr et al., 1998). Many of the fisheries are very dynamic. Landings are driven by the demands of the market, the abundance of the target species, and attempts by the regulators to reduce harvest. As new markets are found for species that were previously unmarketable or of low value, annual landings of those species can increase rapidly. Landings from other fisheries decline as fishermen fill the demands of the new markets. Regulation of fish harvest, entry into a fishery, gear usage, and season length can have a pronounced effect on landings. Fisheries also decline and expand with the cycles of abundance and scarcity of the targeted species. Long-term over-exploitation of many fish stocks along the Pacific Coast has decreased the abundance of adult fishes and recently led to more restrictive regulation of harvest levels. Some regulations were made because of concerns regarding declines in populations. Declines in landings often follow regulatory efforts and may not directly reflect species abundance. Because of the complexity of the forces driving fish harvest in the Monterey Bay area, generalizations about fish abundance based on landing data must be made carefully. CDFG catchblock data from 1975 through 1998 were used for the following analysis of commercially important fish species present in the Monterey Bay region. Because of inconsistencies in catchblock reporting, landings cited for a species or market category by catchblock are generally smaller than landings reported by port.

Fishes and invertebrates are harvested from the Monterey area using a variety of fishing methods. A majority of the fishes landed in Monterey ports between 1975 and 1998 was taken with purse seine and trawl nets. Set gillnets have traditionally been used to harvest California halibut *Paralichthys californicus*, rockfish *Sebastes* spp., white croaker *Genyonemus lineatus*, and a variety of sharks. Commercial fishermen use trolling gear to harvest salmon and albacore during the seasons when they are abundant in the area. Hook- and line- gear has traditionally been used to harvest rockfish *Sebastes* spp. and lingcod *Ophiodon elongatus* over rocky reefs near the canyon. Set longlines, which are now prohibited in nearshore waters (within 1 mile), are used in the Monterey canyon area to take sablefish *Anoplopoma fimbria* and grenadier (Family Macrouridae). Fish traps and "stick gear" are used in the recently established live rockfish fishery. Traps are also used to take rock crabs *Cancer* spp. and Dungeness crab *Cancer magister*.

The most effective gear for certain species, in terms of biomass harvested, is the purse seine. Purse seining is used to harvest pelagic species such as market squid *Loligo opalescens*, Pacific sardine *Sardinops sagax*, northern anchovy *Engraulis mordax*, and both Pacific mackerel *Scomber japonicus* and jack mackerel *Trachurus symmetricus*. Market squid has consistently been one of the top two species landed in the Monterey area. Between 10 and 20 million pounds of squid are typically landed at Monterey ports each year. Northern anchovy and Pacific sardine rank second and third in pounds landed, however, the fishery has shifted from northern anchovy, which were abundant in the 1970s and 1980s, to sardines which have dominated the fishery in recent years. Both Pacific mackerel and jack mackerel rank among the top 10 species landed. Pacific mackerel landings peaked in the early 1980s, ranking between first and fifth from 1980 to 1986. Landings of Pacific mackerel have also been high in the Monterey area during the 1990s. Landings of jack mackerel have ranked between second and twelfth for 19 of the past 24 years. Both species of mackerel were also landed in the market category “unspecified mackerel” which ranked first in 1994 and second for the next 2 years. Pacific herring *Clupea pallasi* have also sustained high levels of harvest through most of the period. The fishery is somewhat cyclic and peak landings from the area occurred in 1982, 1987, and 1996. Reported landings of Pacific herring ranged from over 560,000 pounds in 1987 to 52 pounds in 1997 and averaged around 165,000 pounds annually. No landings were reported for the catchblock area during 1991 and 1998.

Commercial trawlers in the area target a variety of demersal fish species, or groundfish. There are several distinctly different trawl fisheries in Monterey Bay. The species targeted depends largely on what permits the boats, or owners/captains have been able to acquire. The harvest of groundfish species is closely regulated by the Pacific Fisheries Management Council and National Marine Fisheries Service. The DTS complex (Dover sole, thornyhead, and sablefish) is targeted only by vessels with federal limited-entry groundfish permits. The harvest of the DTS complex is second to that of purse seiners in terms of biomass. Dover sole *Microstomus pacificus*, which ranked eleventh in total pounds landed between 1975 and 1998, did not rank within the top ten species until 1985. Thornyheads *Sebastolobus* spp. and sablefish are more valuable per pound than Dover sole and these species have recently had more restrictive quotas. Sablefish have consistently sustained high levels of harvest. Longspine thornyheads *Sebastolobus altivelis* and shortspine thornyheads *Sebastolobus alascanus* were not heavily exploited until the mid-1980s, when new markets for the species opened in Japan.

Trawlers with federal groundfish permits also target splitnose *Sebastes diploproa* and aurora rockfish *Sebastes aurora* (Rosefish market category), widow rockfish *Sebastes entomelas*, bocaccio rockfish *Sebastes paucispinis*, chilipepper rockfish *Sebastes goodei,* and Sebastes complex species. The Sebastes complex is composed of a mixture of rockfish species that do not have specific quotas. Sebastes complex species are often landed in the market category "unspecified rockfish." Unspecified rockfish landings consistently rank within the top ten fish categories harvested from the Monterey Bay area. The years of peak harvest for this market category were in the mid-1980s and early 1990s. Bocaccio and chilipepper rockfish landings were combined into one market category until bocaccio became a federally regulated quota species. Bocaccio have sustained consistently high levels of harvest until recently when a decline in their abundance prompted regulators to drastically reduce quotas. Both chilipepper rockfish and the market category rosefish have been heavily exploited in the 1990s. Both were removed from the Sebastes Complex quota and given individual quotas in 1999. Limited entry trawlers also commonly land rex sole *Errex zachirus*, petrale sole *Eopsetta jordani*, English sole *Parophrys vetulus*, lingcod, grenadiers, and skate/skate wings (*Raja* spp.).

Trawlers without a federal groundfish permit also harvest groundfish (except DTS), however, these "Open Access" fishermen are subject to more restrictive quotas. Because of restrictive rockfish quotas, the open access trawl fishery generally targets demersal fish species such as California halibut, white croaker, sole, and Pacific sanddab *Citharichthys sordidus*. Starry flounder *Platichthys stellatus*, turbot *Pleuronichthys* spp., and Pacific angel shark *Squatina californica* are among the non-target species caught in this fishery that are considered saleable by-catch. Sanddab harvest was variable during this period and ranged from 177 pounds in 1984 to nearly 530,000 pounds in 1998. From CDFG catchblock data, the average annual harvest of sanddabs was around 82,000 pounds. Sanddabs ranked twenty first in pounds landed between 1975 and 1998. White croaker are also harvested by open access trawlers and ranked thirteenth overall. Landings of white croaker from the area are somewhat cyclic and ranged from 4,246 pounds in 1984 to nearly 642,000 pounds in 1980. The average annual landing of white croaker from Monterey Bay from 1975 through 1998 is around 180,000 pounds. White croaker consistently ranked among the top ten species harvested in the area (annually) from the mid-1970s through the early 1980s. Pink shrimp *Pandalus eous* and spot prawns *Pandalus platyceros* have become the target of a large number of open access trawlers with shrimp or prawn permits. The pink shrimp fishery is seasonal and highly cyclic. Peaks of harvest and fishing effort are often followed by steep declines in both. Spot prawn harvest in the area consistently remained at a relatively low level (average of less than 9,000 pounds annually) until 1991. Since 1991 the annual harvest has risen steadily to nearly 190,000 pounds (by 1998). The fishery is currently being driven by the high prices paid for live spot prawns.

Gillnets have been an effective gear used in the past to harvest a variety of species. California halibut are the target of the fishery, however, white seabass *Cynoscion nobilis*, white croaker, and several shark species are also regularly landed by gillnetters. Concern over sea otter mortality resulted in regulation of the depth in which gillnets could be set. Currently, gillnets cannot be set inside of 30 fathoms (55 m or 180 ft) of water. The annual harvest of halibut from the area ranged from around 4,000 pounds in 1984 to approximately 180,000 pounds in 1997. The average harvest from 1975 to 1998 was about 57,000 pounds. Gillnet boats targeting rockfish generally set their nets in water depths from 50 to 120 fathoms (91m to 220 m or 300 ft to 720 ft). Rockfish gillnetters target "red" rockfish (vermilion rockfish *Sebastes miniatus*, yelloweye rockfish *Sebastes ruberrimus*, canary rockfish *Sebastes pinniger*, copper rockfish *Sebastes caurinus*, greenspotted rockfish *Sebastes chlorostictus*, etc.) but land large numbers of bocaccio, chilipepper, and bank rockfish *Sebastes rufus*, as well as lingcod. Recent regulation of open access rockfish harvest has eliminated much of the gillnet effort for rockfish.

The commercial troll fleet in the Monterey Bay area targets king salmon *Oncorhynchus tshawytscha* and albacore *Thunnus alalunga* when they are in season and available. The salmon fishery has traditionally been one of the more lucrative fisheries in the bay for small, independent commercial fishermen. King salmon harvested within the area rank within the top ten, in terms of pounds landed annually, for all years (from 1975 to 1998) except 1985 and 1988. King salmon ranked seventh in total pounds landed for the period. Silver salmon *Oncorhynchus kisutch* was the tenth ranked species in 1975. Albacore are caught by trollers in the outer regions of Monterey Bay during years when warmer water is relatively close to land. They consistently ranked within the top ten species landed from the area throughout the 1970s and 1980s. Albacore ranked tenth in total pounds landed from 1975 to 1998. Many boats landing albacore in area ports fished areas outside the bay. Some commercial trollers also target rockfish during the season when salmon fishing is closed. By modifying their gear and fishing methods, these fishermen have traditionally targeted red rockfish but also catch a significant number of bocaccio, chilipepper rockfish, and lingcod. Between 1980 and 1998 annual harvest (for all gears) of red rockfish (market category 959) ranged from 90 pounds to over 250,000 pounds. The average annual harvest (Monterey area) for the group over the last 20 years is approximately 92,000 pounds. The red rockfish market category ranked twenty-fourth in total pounds landed from 1975 to1998.

During the early 1990s a new fishery evolved to supply the market demand for live fish. The fishery targets nearshore rockfish species (grass rockfish *Sebastes rastrelliger*, gopher rockfish *Sebastes carnatus*, brown rockfish *Sebastes auriculatus*, china rockfish *Sebastes nebulosus*, etc.) and cabezon *Scorpaenichthys marmoratus*. Fishes are taken from the intertidal zone down to depths of 30 m (100 ft) with hook and line gear or traps and kept alive in holding tanks. Kelp greenling *Hexagrammos decagrammus* and lingcod are not target species in this fishery, but are commonly landed. Harvest of species from the nearshore reefs within Monterey Bay and coastal areas adjacent to the bay increased dramatically as the fishery expanded. Harvest levels peaked for many species during 1995 and 1996. Over-exploitation of this previously unregulated resource, along with recent regulation, has resulted in a moderate decline in landings for most species.

The Monterey Bay area also supports a moderate-sized crab fishery. Dungeness crab and two species of rock crab are harvested from the Monterey area. Dungeness crab landings vary with the species' abundance near the southern end of its range. Harvest reported from the area ranged from around 1,000 pounds landed in 1988 to approximately 112,000 in 1998. Landings of Dungeness crab from the area have increased significantly in the 1990s and ranked between eleventh and thirteenth in pounds landed annually between 1994 and 1996. Pacific rock crab *Cancer antennarius* and red rock crab *Cancer productus* are typically landed in the combined market category "Unspecified rock crab" or their claws are removed landed in the "crab claws" market category. Rock crab landings are generally small, but ranged from 12 pounds in 1976 to around 134,000 pounds in 1989. There was significant variation in the pounds of crab claws landed. From reported catchblock data between 1986 and 1998, annual landings of crab claws ranged from around 81,200 pounds in 1987 to 1 pound in 1997.

3.0 ENTRAINMENT STUDY AND ASSESSMENT METHODS

Moss Landing Power Plant withdraws water for cooling purposes from an intake located in Moss Landing Harbor. The cooling water is pumped from the harbor through screens that have 3/8 inch (0.9 cm) mesh designed to exclude anything greater than the diameter of the plant's condenser tubes. Entrainment occurs when organisms small enough to pass through the 3/8-in (0.9 cm) mesh are drawn through these screens into the power plant's cooling water system where they are subsequently exposed to stressful conditions — pressure changes, shear forces, thermal changes, chemical changes, and collisions with surfaces.

The major objective of this 316(b) study is to characterize entrainment at the Moss Landing Power Plant's new combined-cycle intake (formerly the Units 1 through 5 intake). Field data on the composition and abundance of potentially entrained larval fishes and cancer crab megalops provide a basis to refine estimates of the total number and types of these organisms passing through the power plant's cooling water intake system. Estimates of fractional losses due to entrainment by the new intake structure were obtained from data collected on source water populations of entrainable fish larvae and *Cancer* spp. megalops.

The modifications to the new combined-cycle intake cooling water flows will alter previously assessed entrainment rates. Data from samples collected in front of the intakes for the new combined-cycle units were used to evaluate entrainment effects. These data were used, assuming 100 percent entrainment mortality, with data collected from the source water to assess the potential impact to fishery resources. The studies were designed to address the following questions:

- Have changes occurred in MLPP's source water bodies that would lead to alteration of the estimates of abundance or distribution of source water stocks of entrainable larval fishes or cancer crab megalops?
- What is the potential impact of the power plant's cooling water system on larval fishes and cancer crabs?

These results also provide site- and species-specific information used to evaluate the potential effectiveness of intake modifications for minimizing the potential effects of entrainment and to evaluate available intake technologies for the new combined-cycle units of the Moss Landing Power Plant.

The Moss Landing Power Plant entrainment studies are focused on fishes (all life stages), *Cancer* spp. (megalopal life stage), and European green crabs *Carcinus maenas* (megalopal life stage). A description of laboratory processing methods is also provided.

3.1 Entrainment Study

This study was designed to quantify the current composition and abundance of entrained larval fishes and European green and cancer crab megalops at MLPP. Planktonic fish eggs were not quantified in this study. Although there are descriptions of many marine eggs, the taxonomy remains difficult and is very time consuming.

3.1.1 Entrainment Sampling Methods

Towed net sampling began March 2, 1999 and continued through February 24, 2000. Samples taken from in front of the intakes for the new combined-cycle units and for Units 6 and 7 were collected by towing a bongo frame with 0.71 m (2.3 ft) diameter openings and equipped with two 335 µm mesh plankton nets and codends. Samples were collected over a continuous 24-hour period; each period was divided into six, 4-hour sampling cycles. Two tows were conducted during each cycle. Samples were collected at stations located directly in front of the intake structures for both the new combined-cycle units and for Units 6 and 7 (Figure 3-1). Sample collection methods were similar to those developed and used by the California Cooperative Oceanic and Fisheries Investigation (CalCOFI) in their larval fish studies (Smith and Richardson, 1977). The bongo nets were lowered as close to the bottom as possible. Once the nets were at the correct depth, the boat was moved forward and the nets retrieved at an oblique angle (winch cable at a 45° angle). The winch retrieval speed was constant at approximately 1 ft/sec. Each net mouth was fitted with a calibrated flowmeter to record the water volume filtered.

The target water volume filtered by both bongo nets combined was 40 m^3 (20 m^3/net). The sample volume was checked when the nets reach the surface. If the target volume was not collected, the nets were placed back in the water and the tow repeated so that the targeted volume was reached. Upon successful completion of a tow, the nets were retrieved from the water and all of the collected material was rinsed into the codend. The contents of both nets were combined into a single, labeled jar (constituting one sample) immediately after collection and were preserved in ethanol (ETOH). Preservation using ETOH allows specimen identifications to be genetically validated or allows for age and growth studies should the need arise. Each sample was given a serial number based on the location, date, time, and depth of collection. In addition, that information was logged onto a sequentially numbered data sheet. The sample's serial number was used to track it through laboratory processing, data analyses, and reporting.

Sampling at the new combined-cycle units and Units 6 and 7 intakes occurred once per week during the peak larval fish season (November through June) and every other week during the off-peak period (Section 3.1.2). All of the entrainment samples collected from the new CC units and the Units 6 and 7 intakes have been sorted and all of the larval fishes and targeted crabs have been identified. Quality control resorts and taxonomic re-identifications are nearly complete.

Similarity was tested for fish data from all surveys (Surveys 1 through 42) from samples collected in front of the two intake complexes. The results of these tests are discussed in Section 4.

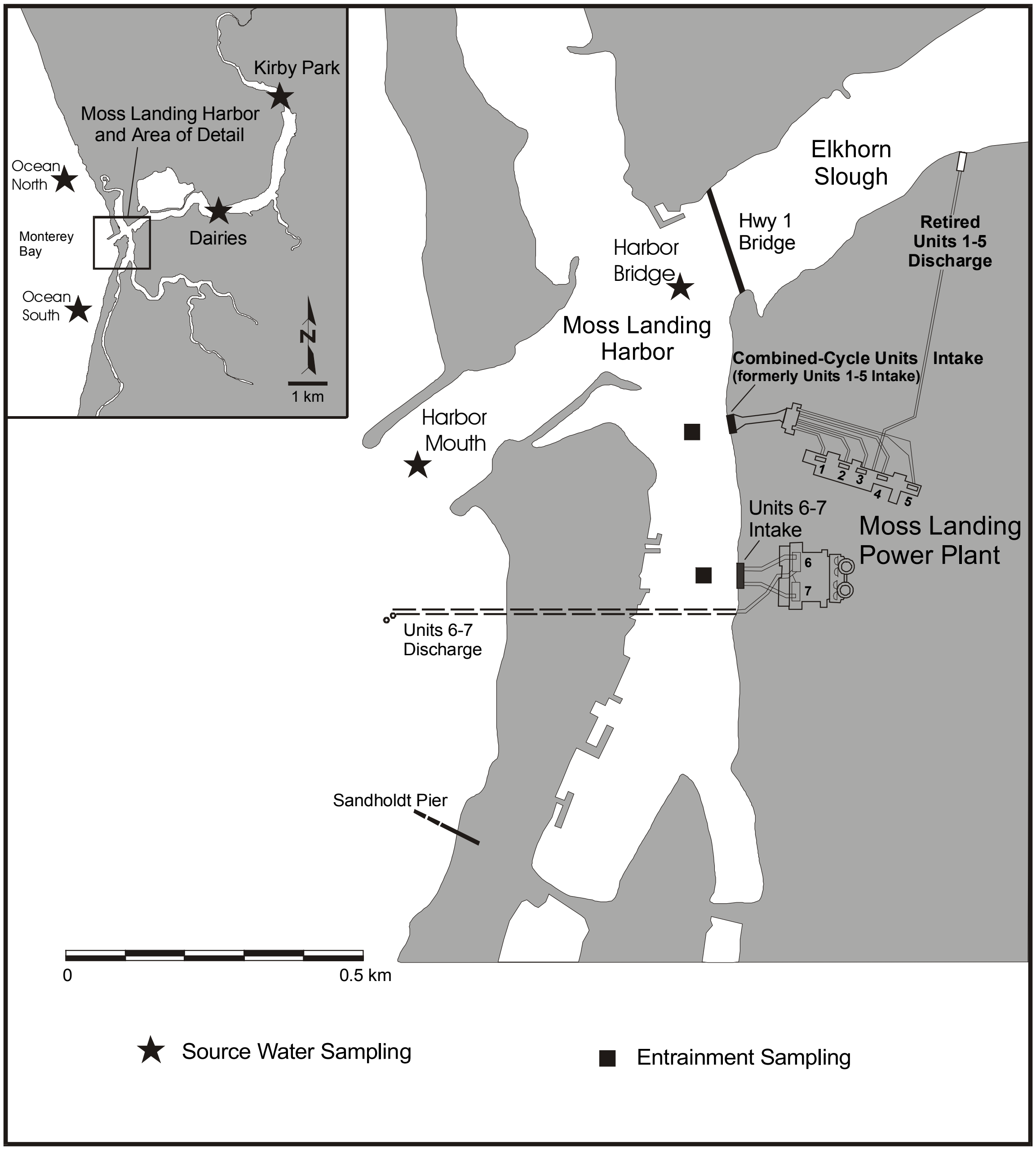


Figure 3-1. Moss Landing Power Plant sampling locations.

3.1.2 Entrainment Sampling Frequency Rationale

Using peak periods of larval abundance from a previous MLPP entrainment study (PG&E, 1983; Table 3-1), a rationale was developed for the proposed sampling frequency. The eight taxa presented in Table 3-1 represent 94 percent of the total abundance of larval fishes entrained during the years 1978-1980. The observed seasonality of larval abundance from MLPP (PG&E, 1983) corresponds well to reported seasonality from the literature on larval fishes (Matarese et al., 1989; Moser, 1996) and with a previous study conducted in 1974 – 1978 near the site of the present survey effort (Yoklavich et al., 1992). Thus, it was proposed to concentrate the sampling efforts (one 24-hr period per week) during the periods of peak larval abundance observed at MLPP for the majority of the eight taxa represented in Table 3-1. Specifically, increased sampling efforts from the beginning of November through the end of June (i.e., greater collection frequency) encompassed the majority of spawning peaks for these eight taxa. Notably, the observed spawning peak for longjaw mudsucker is not encompassed within the months described above. However, the year-round presence and continuation of biweekly sampling during the remainder of the year (July through October) is expected to adequately document the presence and abundance of this species.

Table 3-1. Common Entrainment Period and Peak Concentrations, in order of Abundance, for the Eight Most Abundantly Entrained Larval Fish Taxa at MLPP during 1978–1980 (PG&E, 1983).

Name	Most Common Entrainment Period	Peak Concentration (number/ m^3)
Northern anchovy (*Engraulis mordax*)	November to April	5.4 (March)
Gobies (Gobiidae)	Year-Round	2.5 (January)
Silversides (Atherinidae)	November to April	2.7 (March)
Smelts (Osmeridae)	January to September	4.2 (February)
Pacific Staghorn sculpin (*Leptocottus armatus*)	September to May	0.5 (February)
White croaker (*Genyonemus lineatus*)	August to April	0.7 (November and December)
Longjaw mudsucker (*Gillichthys mirabilis*)	Year-Round	0.5 (September and October)
Pacific herring (*Clupea pallasi*)	Two spawning periods: December to March and May to Early August	0.5 (January) and 1.3 (June)

3.2 Source Water Study

3.2.1 Source Water Sampling Methods

The study was designed to characterize the source water composition, abundance, and distribution of larval fishes and megalopal stages of *Cancer* spp. and European green crabs. The entrainment concentrations and intake volumes were compared to source water concentrations and source water volumes to provide estimates of fractional loss as well as assist in the definition of source population boundaries. A description of how the source water volumes were calculated is presented in Section 6.

Samples were collected at six stations (Table 3-2) monthly in one of two ways; oblique tows for the ocean and harbor stations and push nets for the Kirby Park and Dairies stations. The locations for the source water stations are shown in Figure 3-1. The following three stations were chosen to conform to locations previously studied by Nybakken et al. (1977): (1) between the Highway 1 Bridge and the entrance to the Moss Landing Harbor, (2) near the Dairies, and (3) near Kirby Park. The remaining three station locations were chosen based on discussions with the Technical Work Group during the September 15, 1999 meeting. One additional station was added in the mouth of the entrance and one ocean station located approximately one mile (1.6 km) to the north of the harbor entrance and one ocean station located approximately one mile (1.6 km) to the south of the harbor entrance (Figure 3-1). Two samples of at least 40 m^3 were collected in daylight at each station during one high and one low tide. Source water sampling was scheduled to occur during the same 24-hour period as the entrainment collections. Sampling at the harbor entrance and ocean stations consisted of an oblique tow using the same methodology described above. Sampling at the Dairies and Kirby Park stations (Figure 3-1) consisted of pushing a 0.71 m (2.3 ft) diameter net of 335 μm mesh on the surface in front of a moving boat. All source water samples were processed in the laboratory.

Additional sampling of the Harbor Mouth and Harbor Bridge stations was requested by the TWG at the January 18, 2000 meeting. The sampling of these stations will be conducted during the same cycles as the entrainment sampling at the intakes. These additional data will be used to provide more information about the diel distribution of larval fishes.

Table 3-2. Collection Specifications for Source Water Sampling at MLPP.

Station Name	Description	Location (Lat. / Long.)	Station Depth at MLLW (m / ft)
Ocean North	One mile north of ML harbor mouth, at the 20-meter depth contour.	36° 48.84' N / 121° 48.40' W	20 m / 66 ft
Ocean South	One mile south of ML harbor mouth, at the 20-meter depth contour.	36° 47.44' N / 121° 48.52' W	20 m / 66 ft
Harbor Mouth	Entrance to Moss Landing Harbor from Monterey Bay; between the north and south breakwaters.	36° 48.38' N / 121° 47.40' W	7 m / 23 ft
Harbor Bridge	Moss Landing Harbor channel at Highway 1 bridge.	36° 48.292' N / 121° 47.150' W	7 m / 23 ft
Units 6 and 7 Intake	Moss Landing Harbor channel at MLPP Units 6 and 7 intake structure.	36° 48.292' N / 121° 47.130' W	5.5 m / 18 ft
Dairies	Elkhorn Slough main channel about 2.2 km (1.4 miles) inland from the Highway 1 bridge.	36° 48.74' N / 121° 45.70' W	4 m / 13 ft
Kirby Park	Elkhorn Slough main channel about 6.2 km (3.9 miles) inland from the Highway 1 bridge.	36° 50.40' N / 121° 44.75' W	3 m / 10 ft

3.2.2 Comparability of Surface and Oblique Towed Methodologies

Similar to past studies, the MLPP larval fish studies used two different types of sampling gear to collect samples. Both types were selected to solve a particular sampling challenge associated with different station locations.

Obliquely towed nets collect a bottom-to-top water column sample and pushed nets sample a fixed depth, typically at the surface. In the case of the MLPP studies, both gear types used plankton nets that were equipped with 335 µm mesh to collect the same size of planktonic organisms and used calibrated flowmeters to measure the volume of the sample. It is not expected that sampling efficiency will vary significantly between obliquely-towed nets and pushed nets. Although obliquely towed nets vs. pushed nets would be presented with different water to sample, it is unlikely that the samples collected by the two different methods would produce statistically different estimates of the water column’s larval concentrations. Both types of gear had the same diameter net mouths, used the same mesh net, had reduced (McGowan and Brown, 1966) or no bridle effects (e.g., push net), and were towed at the same speeds.

These nets are designed to sample plankton efficiently and to minimize biases commonly associated with sampling planktonic organisms (McGowan and Brown, 1966; Tranter and Smith, 1968). They are conical (widest at the opening) which promotes tumbling of planktonic organisms down the net sides toward the codend as water is filtered out and away from the net axis. This type of filtration also has the advantage of causing very little damage to the planktonic organisms aiding in both the laboratory processing and identification phases of sample analysis.

However, the fine mesh size of these nets (335 μm) makes them susceptible to clogging under certain conditions (e.g., algal blooms or high turbidity). Clogged nets can be preceded by a pressure wave reducing filtration efficiency, warning mobile zooplankters of the net's approach (McGowan and Brown, 1966), and introducing unmeasured bias into the resulting samples due to avoidance and escapement.

Larval fishes and other planktonic organisms have patchy vertical distributions (e.g., Schlotterbeck and Connally, 1982; Brewer and Kleppel, 1986; Gray, 1993; Moser and Smith, 1993; Gray, 1998) which present unique challenges to representative sampling. The rationale for the use of an oblique tow is that the vertical concentrations of larval fishes vary significantly in the water column and sampling at only one depth would produce a sample bias when estimating total water column abundance. For instance, variations in vertical current stratification or distribution of planktonic organisms are integrated by the representative sampling of each sampling stratum (Simpson, 1959; Smith et al., 1968). The pushed net, while fished at a fixed depth, is used in shallow areas where turbulent tidal flow potentially eliminates water column stratification of larvae (i.e., the vertical larval distribution should be homogeneous).

Vertical distribution differences are integrated when using an obliquely-towed net and sampling the entire water column and are nullified by shallow water turbulent mixing in the case of the pushed-net sampling. It is expected that obliquely towed net samples at the deeper Moss Landing Harbor sampling locations and pushed-net samples at the shallow Elkhorn Slough sampling location will be similarly representative of water column plankton concentrations. Furthermore, if slight differences exist between the towed and pushed nets, it is probable that these differences could not be statistically detected.

3.3 Laboratory Processing and Data Handling

During laboratory processing all larval fishes and the megalopal stage of *Cancer* spp. were removed from the samples. European green crab *Carcinus maenas* megalops were searched for and removed from the samples. Fish eggs were not removed from the samples. Although there are descriptions of many marine eggs, the taxonomy remains difficult and time consuming. Larval fishes and targeted crab species megalops were identified to the lowest taxonomic level possible by TENERA's in-house taxonomists. In addition, the lifestages of larval fishes were identified and recorded on the data sheet. A laboratory quality control (QC) program for all levels of laboratory sorting and taxonomic identification was applied to all samples. The QC program also incorporated the use of outside taxonomic experts to provide taxonomic QC and resolve taxonomic uncertainties.

Lengths of larval bay goby and longjaw mudsucker were obtained using a computer imaging system and Optimas image analysis software. A quality assurance program was maintained for the system operator. The image analysis software was interfaced directly to Microsoft Excel and subsequently linked to the MLPP database in Microsoft Access.

Laboratory data sheets were coded with species or taxon codes. These codes were verified against species/taxon lists and signed off by the data manager. The data were then entered into a computer database for analysis.

3.4 Sampling Sufficiency

Species accumulation curves were calculated to assess the adequacy of the sampling effort (Krebs, 1989). A species accumulation curve depicts the number of new species (species not encountered before) collected during repeated sampling efforts. It is in effect a running tally of the number of species collected. The tally is cumulative so each species is counted only once. Generally, the slope of a species accumulation curve is steepest during early sampling efforts when new species are frequently encountered. As sampling continues fewer new species are collected so the slope of the curve tends toward zero. This trend may be confounded when computing a species accumulation curve over time and when sampling larval fishes, due to the reproductive cycles of species within the community. Species accumulation curves were computed from the mean, maximum, and minimum number of species sampled from 1,000 random iterations of the data to help account for seasonal differences in reproductive cycles among species. Results are presented in Section 4.1.1.

3.5 Assessment Methods

Larval sampling at the cooling water intakes at the new combined-cycle units provided periodic estimates of daily as well as annual larval entrainment at the MLPP. Estimates of entrainment loss, in conjunction with demographic data collected from the fisheries literature, permits modeling of adult equivalent loss (*AEL*) and fecundity hindcasting (*FH*). Additional sampling at the potential source populations of larvae in the source water areas of Moss Landing Harbor, Elkhorn Slough, and Monterey Bay provides the information that is combined to estimate a total annual harvest mortality probability using the Empirical Transport Model (*ETM*). Considering the guidelines established in the EPA draft document (EPA, 1977) and given the constraints of the data and available demographic information for the larvae entrained, the TWG will determine which taxa within these groups will be included in more detailed analyses of entrainment effects when sufficient data have been collected. The data requirements, assumptions, outputs, advantages, and disadvantages of these approaches are summarized in Tables 3-3 and 3-4. In the

MLPP 316(b) study, we will use each approach (i.e., *AEL*, *FH*, and *ETM*) as appropriate for each taxon to assess effects of entrainment losses.

3.5.1 Demographic Approaches

Adult equivalent loss models evolved from impact assessments that compared power plant losses to commercial fisheries harvests and/or estimates of the abundance of adults. In the case of adult fishes impinged by intake screens, the comparison was relatively straightforward. To compare the numbers of impinged sub-adults and juveniles and entrained larval fishes to adults, it was necessary to convert all these losses to adult equivalents. Horst (1975) provided an early example of the equivalent adult model (*EAM*) to convert numbers of entrained early life stages of fishes to their hypothetical adult equivalency. Goodyear (1978) extended the method to include the extrapolation of impinged juvenile losses to equivalent adults.

Demographic approaches, exemplified by the *EAM*, produce an absolute measure of loss beginning with simple numerical inventories of entrained or impinged individuals and increasing in complexity when the inventory results are extrapolated to estimate numbers of adult fishes, adult crabs, or biomass. We will use two different but related demographic approaches in assessing entrainment effects at MLPP: *AEL*, which expresses effects as absolute losses of numbers of adults, and *FH*, which estimates the number of adult females whose reproductive output has been eliminated by entrainment of larvae and megalops.

Age-specific survival and fecundity rates are required for *AEL* and *FH*. Adult-equivalent loss estimates require survivorship estimates from the age at entrainment to adult recruitment; *FH* requires egg and larval or megalopal survivorship until entrainment. Furthermore, to make estimation practical, the affected population is assumed to be stable and stationary, and age-specific survival and fecundity rates are assumed to be constant over time. Each of these approaches provides estimates of adult fish and crab losses that may still need to be placed into context regarding standing fish/crab stocks.

Species-specific survivorship information (e.g., age-specific mortality) from egg, larvae, and megalop to adulthood is limited for many of the taxa likely to be considered in this assessment. Thus, in many cases, these rates must be inferred from the literature along with their measures of uncertainty. Uncertainty surrounding published demographic parameters is seldom known and rarely reported, but the likelihood that it is very large should be considered when interpreting results from the demographic approaches for estimating entrainment effects. For some well-studied species (e.g., northern anchovy *Engraulis mordax*), portions of their early mortality schedules and fecundity have been reported (e.g., Parker, 1980; Zweifel and Smith, 1981; Hewitt, 1982; Hewitt and Methot, 1982; Hewitt and Brewer, 1983; Lo 1983, 1985, 1986; McGurk, 1986). Because the accuracy of the estimated entrainment effects from *AEL* and *FH* will depend on the accuracy of age-specific mortality and fecundity estimates, lack of demographic information may limit the utility of these approaches.

Table 3-3. Data Requirements and Outputs for Three Approaches Proposed to Estimate Effects of Cooling Water Withdrawals at MLPP.

Approach	Data Required	Assumptions	Output
Proportional Entrainment (*PE*)	• Taxon-specific estimates of entrainment losses. • Comparable life-stage estimates of taxon's abundance (concentration) in source water.	• Source water samples are representative of the composition and abundance of larvae and megalops in the study area. • Entrainment samples are representative of the organisms entrained in the cooling water.	• Estimated fraction of larval and megalopal concentration removed from the source water by entrainment.
Adult Equivalent Loss (*AEL*)	• Taxon-specific estimates of entrainment and impingement losses. • Age-specific mortality schedules for selected taxa from entrainment-impingement to some predetermined life stage (e.g., recruitment). • Fishery resource abundance estimates for relative impact assessments.	• Age-specific mortality rates are constant for the population. • Population at long-term equilibrium for relative impact assessments (not required for calculations). • Entrainment samples are representative of the organisms entrained in the cooling water.	• Number of animals that would have survived to adulthood had they not been entrained or impinged by the intake.
Fecundity Hindcast (*FH*)	• Taxon-specific estimates of entrainment and impingement losses. • Species- and age-specific adult fecundity. • Age-specific mortality schedules for selected taxa from parturition/hatch to entrainment/impingement.	• Age-specific mortality rates are constant for the population. • Population at long-term equilibrium for relative impact assessments (not required for calculations). • Entrainment samples are representative of the organisms entrained in the cooling water.	• Number of sexually mature females represented by the losses of reproductive output due to entrainment and/or impingement.

Table 3-4. Advantages and Disadvantages of the Three Approaches Proposed to Estimate Effects in the MLPP 316(b) Assessment.

Approach	**Advantages**	**Disadvantages**
Proportional Entrainment (*PE*)	• Empirical estimate of *PE* compares larvae or megalops entrained to larvae or megalops in the source water. • Age- and species-specific survivorship data not required.	• Monterey Bay taxa (e.g., *Genyonemus lineatus*) not adequately sampled in present design. • Local adult population sizes not well described by fishery catch data for mixed species (e.g., *Sebastes* spp., Pleuronectidae, etc.). • Scaling intake effects up to population level impacts will be problematic.
Adult Equivalent Loss (*AEL*)	• Entrainment/impingement losses are expressed as adults facilitating the interpretation of population-level impacts. • Common usage in 316(b) studies.	• Difficult to interpret for entrained organisms in broad taxonomic categories (e.g., *Gobiidae* spp.) containing multiple life-histories. • Age- and species-specific mortality data are little known or unavailable for many organisms that are entrained/impinged by the intakes. • Local adult population sizes not well described by fishery catch data for mixed species (e.g., *Sebastes* spp., Pleuronectidae, etc.).
Fecundity Hindcast (*FH*)	• Entrainment/impingement losses are expressed as adults facilitating the interpretation of population-level impacts.	• Age- and species-specific mortality data are little known or unavailable for many organisms that are entrained/impinged by the intakes. • Local adult population sizes not well described by fishery catch data for mixed species (e.g., *Sebastes* spp, Pleuronectidae, etc). • Scaling intake effects up to population level impacts will be problematic. • Age- and species-specific fecundity data have not been previously reported for many organisms that are entrained/impinged by intakes.

The precursor to the *AEL* and *FH* calculations is an estimate of total annual larval and megalopal entrainment. An estimate of larval and megalopal entrainment at the new combined-cycle units intake will be based on periodic tow samples with total annual entrainment at MLPP expressed as

$$\hat{E}_T = \hat{E}_{CC} \tag{1}$$

where $\hat{E}_{CC}$ is the estimate of total entrainment at the new combined-cycle units intake (Appendix A). Estimates of total entrainment at the intake are based on two-stage sampling designs, with days within periods and replicate tows within days. The within-day sampling is based on a stratified random sampling scheme with 4 temporal strata corresponding to tidal flows (Appendix A).

3.5.1.1 Adult Equivalent Loss (*AEL*)

The *AEL* approach uses estimates of the abundance of the entrained or impinged organisms (i.e., $\hat{E}_T$) to project the loss of equivalent numbers of adults based on mortality schedules and age-at-recruitment. The primary advantage of this approach is that it translates power plant-induced early life-stage mortality into numbers of adult fishes and adult cancer crabs that are familiar units to resource managers. Adult equivalent loss does not require source water estimates of larval or megalopal abundance in assessing effects. This latter advantage may be offset by the need to gather age-specific mortality rates to predict adult losses and the need for information on the adult population of interest for estimating population-level effects (i.e., fractional losses). However, the need for age-specific mortality estimates can be reduced by various forms of approximation as show by Saila et al. (1997). They describe an *AEL* and apply it to six years of entrainment and two years of impingement data for winter flounder *Pleuronectes americanus*, red hake *Urophycis chuss*, and pollock *Pollachius virens* at the Seabrook Station, in New Hampshire, and contrast these with equivalent adult losses of winter flounder at Pilgrim Station, another coastal power plant. Their model assumes an adult population at equilibrium, a stable age distribution, a constant male:female ratio, and an absence of density-dependent (i.e., compensatory) mortality between entrainment and recruitment to the adults.

Starting with the number of age class i larvae entrained $\left(\hat{E}_i\right)$, it is conceptually easy to convert these numbers to an equivalent number of adults lost $\left(A\hat{E}L\right)$ at some specified age class from the formula:

$$A\hat{E}L = \sum_{i=1}^{n} \hat{E}_i S_i \tag{2}$$

where

n = number of age classes;
$\hat{E}_i$ = estimated number of larvae and megalops lost in age class i; and
S_i = survival probability for the ith class to adulthood (Goodyear, 1978).

Age-specific survival rates from larval and megalopal stages to recruitment into the fishery must be included in this assessment method. For some commercial species, natural survival rates are known after the fishes or crabs recruit into the commercial fishery. For the earlier years of development, this information is not well-known and may be lacking for non-commercial species.

The information on survival probabilities in Equation (2) will likely be unknown, in which case a simplified *AEL* expression can be written as

$$A\hat{E}L = \hat{E}_T \cdot \hat{S}_A \tag{3}$$

where

$\hat{S}_A$ = survival from the average age of larval entrainment to adulthood.

The exact variance for Equation (2) can be expressed as

$$Var\left(A\hat{E}L\right) = E_T^2 \cdot Var\left(\hat{E}_T\right) + S_A^2 \cdot Var\left(\hat{S}_A\right) + Var\left(\hat{E}_T\right) \cdot Var\left(\hat{S}_A\right).$$

The behavior of estimator (3) for *AEL* appears log-linear, suggesting that an approximate confidence interval can be based on the assumptions that ln($A\hat{E}L$) is normally distributed and uses the pivotal quantity

$$Z = \frac{\ln A\hat{E}L - \ln AEL}{\sqrt{\dfrac{V\hat{a}r(A\hat{E}L)}{A\hat{E}L^2}}} \quad .$$

A 90 percent confidence interval for *AEL* was estimated by solving for *AEL* and setting *Z* equal to ±1.645, i.e.

$$A\hat{E}L \cdot e^{-1.645\sqrt{\frac{V\hat{a}r(A\hat{E}L)}{A\hat{E}L^2}}} \text{ to } A\hat{E}L \cdot e^{+1.645\sqrt{\frac{V\hat{a}r(A\hat{E}L)}{A\hat{E}L^2}}} \quad .$$

3.5.1.2 Fecundity Hindcasting (*FH*)

The *FH* approach compares larval and megalopal entrainment losses with adult fecundity to estimate the amount of adult female reproductive output eliminated by entrainment and thereby hindcasts the numbers of adult females effectively removed from the reproductively active population. The accuracy of these estimates of effects, as with those of the *AEL* above, is dependent upon accurate estimates of age-specific mortality from the egg and early larval or megalopal stages to entrainment. If it can be assumed that the adult population has been stable at some current level of exploitation and that the male:female ratio is constant and 50:50, then fecundity and mortality are integrated into an estimate of loss by converting entrained larvae and megalops back into females (i.e., hindcasting).

A potential advantage of *FH* is that survivorship need only be estimated for a relatively short period of the larval stage (i.e., egg to larval or megalopal entrainment). The method requires age-specific mortality rates and fecundities to estimate entrainment effects and some knowledge of the abundance of adults to assess the fractional losses these effects represent. This method assumes that the loss of a single female's reproductive potential is equivalent to the loss of an adult fish or crab which may be inaccurate.

In the *FH* approach, the total of larval entrainment for a species $\left(\hat{E}_T\right)$ will be projected backward to estimate the number of breeding females required to provide the numbers of larvae and megalops seen in the entrainment samples. The estimated number of breeding females $\left(\hat{F}H\right)$ whose fecundity is equal to the total loss of entrained larvae and megalops would be calculated as follows:

$$\hat{F}H = \frac{1}{\hat{\bar{F}}_T} \sum_{j=1}^{w} \frac{\hat{E}_j}{S_j} \tag{5}$$

where

w = number of weeks the larvae or megalops are vulnerable to entrainment;

$\hat{E}_j$ = estimated total entrainment for the *j*th week $(j = 1, \ldots, w)$;

S_j = survival rate from eggs to larvae of the stage present in the *j*th week $(j = 1, \ldots, w)$;

$\hat{\bar{F}}_T$ = average total lifetime fecundity for females, equivalent to the average number of eggs spawned per female over their reproductive years.

The two key input parameters in Equation (5) are fecundity $\hat{\bar{F}}_T$ and very early survival rates $\left(S_j\right)$ from spawning to week *j* of the survey. Descriptions of these parameters may be limited for many species and are a possible limitation of the method. Typically, the information for the fine-grained age structure of the Equation (5) will not be available, and the *FH* calculations will be reduced to

$$\hat{FH} = \frac{\hat{E}_T}{\hat{\bar{F}}_T \hat{S}_L} \tag{6}$$

where

S_L = survival from egg to the average age of larval entrainment.

The variance for the *FH* calculations [Equation (6)] is

$$Var\left(\hat{FH}\right) \doteq (FH)^2 \left[CV\left(\hat{E}_T\right)^2 + CV\left(\hat{\bar{F}}_T\right)^2 + CV\left(\hat{S}_L\right)^2 \right] \tag{7}$$

where, in general,

$$CV\left(\hat{\theta}\right)^2 = \frac{Var\left(\hat{\theta}\right)}{\hat{\theta}^2}.$$

The behavior of estimator (7) for *FH* appears log-linear, suggesting that an approximate confidence interval can be based on the assumptions that ln($\hat{FH}$) is normally distributed and uses the pivotal quantity

$$Z = \frac{\ln \hat{FH} - \ln FH}{\sqrt{\frac{\hat{Var}(\hat{FH})}{\hat{FH}^2}}} \quad .$$

A 90 percent confidence interval for *FH* was estimated by solving for *FH* and setting *Z* equal to ±1.645, i.e.

$$\hat{FH} \cdot e^{-1.645\sqrt{\frac{\hat{Var}(\hat{FH})}{\hat{FH}^2}}} \text{ to } \hat{FH} \cdot e^{+1.645\sqrt{\frac{\hat{Var}(\hat{FH})}{\hat{FH}^2}}} \quad .$$

3.5.2 Empirical Transport Model (ETM)

The empirical transport model (*ETM*) has been proposed by the U.S. Fish and Wildlife Service to estimate mortality rates resulting from cooling water withdrawals at power plants (Boreman et al., 1978, 1981). Variations of this model have been discussed in MacCall et al. (1983) and used to assess impacts (Parker and DeMartini, 1989). The *ETM* has been used to assess impacts at the Salem Nuclear Generating Station in Delaware Bay, New Jersey (PSE&G, 1993) as well as other power stations along the East Coast. The *ETM* approach was also used at the Diablo Canyon Power Plant in central California. We will employ a method similar to that described by MacCall et al. (1983) and used by Parker and DeMartini (1989) while under contract to the Marine Review Committee in their final report to the California Coastal Commission (Murdoch et al., 1989) for San Onofre Nuclear Generating Station on the coast of southern California.

Empirical transport modeling permits the estimation of annual conditional mortality due to entrainment while accounting for the spatial and temporal variability in distribution and vulnerability of each life stage to power plant withdrawals. The generalized form of *ETM* incorporates many time-, space-, and age-specific estimates of source water larval and megalopal mortality as well as information regarding spawning periodicity and duration, most of which are limited or unknown for the marine taxa being investigated.

At MLPP, the larval and megalopal source population has *a priori* been defined as those larvae and megalops in the Monterey Bay, Moss Landing Harbor, and Elkhorn Slough as shown in Figure 3-2.

3.5.2.1 Source Water and Receiving Water Volumes

A variety of methods were used to estimate the volumes of the source and receiving water bodies associated with the Moss Landing Power Plant. The methods used to determine the static water volumes of Moss Landing Harbor, Elkhorn Slough, and a prescribed nearshore portion of Monterey Bay (ocean source water) are presented below. Where it is applicable, the methods used to determine the daily tidal exchange of the individual water bodies are also given.

Monterey Bay (nearshore) / MLPP Ocean Source Water

The volume of Monterey Bay water providing MLPP cooling water was estimated by two methods. The first method was based on the rationale that the majority of entrained bay species originated in the shallow bay habitats in contact with nearshore currents reaching the harbor entrance. Ocean bottom depths immediately in front of the harbor's entrance plunge rapidly into the Monterey Canyon. The bay's depths to the north and south shoal to become broad sand and mud bottom plains characteristic of the bays' nearshore habitat for white croaker and Pacific staghorn sculpin; the only bay species appearing in MLPP entrainment samples in any number. The volume of this nearshore, source-water habitat was calculated for the area one kilometer north and one kilometer south of the harbor entrance out to a depth of 50 m. In discussions with the Technical Working Group and California Energy Commission staff, it was agreed to bound our estimate of Monterey Bay source water volume based on habitat with the daily tidal exchange volume of the harbor/slough.

Methods and sources of information used to estimate this range of Monterey source water volume are described here. For the purposes of this study, the nearshore waters of Monterey Bay/MLPP ocean source waters are defined as those lying along a shoreline reach of 2,000 m to the north and south of the Moss Landing Harbor entrance and extending out to a depth of 50 m (Figure 3-2). The volume of this water body was calculated using the information provided by the National Oceanic and Atmospheric Administration (NOAA) chart # 18685 (31st edition, May 16, 1998). The area described above was inscribed on the chart and then subsequently divided into small sectors of simple geometric shapes. The size of the sectors was dependent upon the nature of the complexity of the bottom characteristics within the sector. Areas with large expanses of bottom topography having fairly uniform slopes were enclosed within suitably large geometric sectors. Areas with more complex bottom topography, like those in the vicinity of the Monterey submarine canyon, were enclosed in relatively small sectors. The purpose of this exercise was to provide sectors that were of a size that allowed easy estimation of the average depth within the sector. When this was completed the surface area of each sector and its volume, based on the average depth within the sector, were calculated. When the sector volumes were totaled, the ocean source water volume was determined to be 275 x 10^6 m^3. It should be noted that the depth soundings found on NOAA chart #18685 are given at Mean Lower Low Water (MLLW) (0.0 feet). The volumes of the other water bodies associated with the MLPP (see below) were subsequently adjusted to be representative of tidal conditions equivalent to Mean Sea Level (MSL) (+2.7 feet). The ocean source water volume, however, is little affected by tidal fluctuations since the border that defines its area, the 50-m isobath, also fluctuates in position with the rise and fall of the tides.

Moss Landing Harbor

The volume of Moss Landing Harbor was determined using methods similar to those used to determine the volume of the Monterey Bay nearshore /ocean source water. Depth soundings were again taken from NOAA chart #18685. The chart also contains detailed information on the dredge depths of the boat channels and turning basins within the harbor. The harbor was defined as the area from the ends of the breakwaters (harbor mouth) east to the mouth of Elkhorn Slough (Highway 1 bridge) and included the north and south arms of the navigable harbor (Figure 3-2). The harbor was divided into geometric sectors and the average depth, surface area, and sector volume were then calculated. The total volume of the harbor at MLLW was determined to be 770,000 m^3. The volume of the harbor at MSL was calculated by multiplying the total surface area of the harbor by the difference in tidal height between MSL and MLLW (2.7 feet) and adding the resulting number to the MLLW volume. Volume at MSL was calculated to be 1.15 x 10^6 m^3. Daily tidal exchange for the harbor alone was calculated to be 1.03 x 10^6 m^3 based on a mean tide range of 3.6 feet and the calculated harbor area.

Elkhorn Slough

In the 1983 316(b) Demonstration report, Pacific Gas and Electric Company listed the total volume of Elkhorn Slough at MSL to be 4.8 x 10^6 m^3 (PG&E, 1983). Since that time channel erosion, accompanied by dike and levee breaches, have increased the total surface area and tidal volume of the system (Figure 3-2). Malzone and Kvitek (1994) reported a 43 percent increase in tidal volume and a 48 percent increase in the total surface area of the system over the decade preceding their work. Based on bathymetric surveys conducted in 1993 and direct tidal measurements taken within the slough, they calculated the total tidal volume of the system to be 5.55×10^6 m^3. This equates to a daily (25-hr) tidal exchange of 11.1×10^6 m^3 for the slough system. Using the data collected during the 1993 surveys, Malzone (1999) calculated the total volume of the Elkhorn Slough system to be 10×10^6 m^3 at MSL.

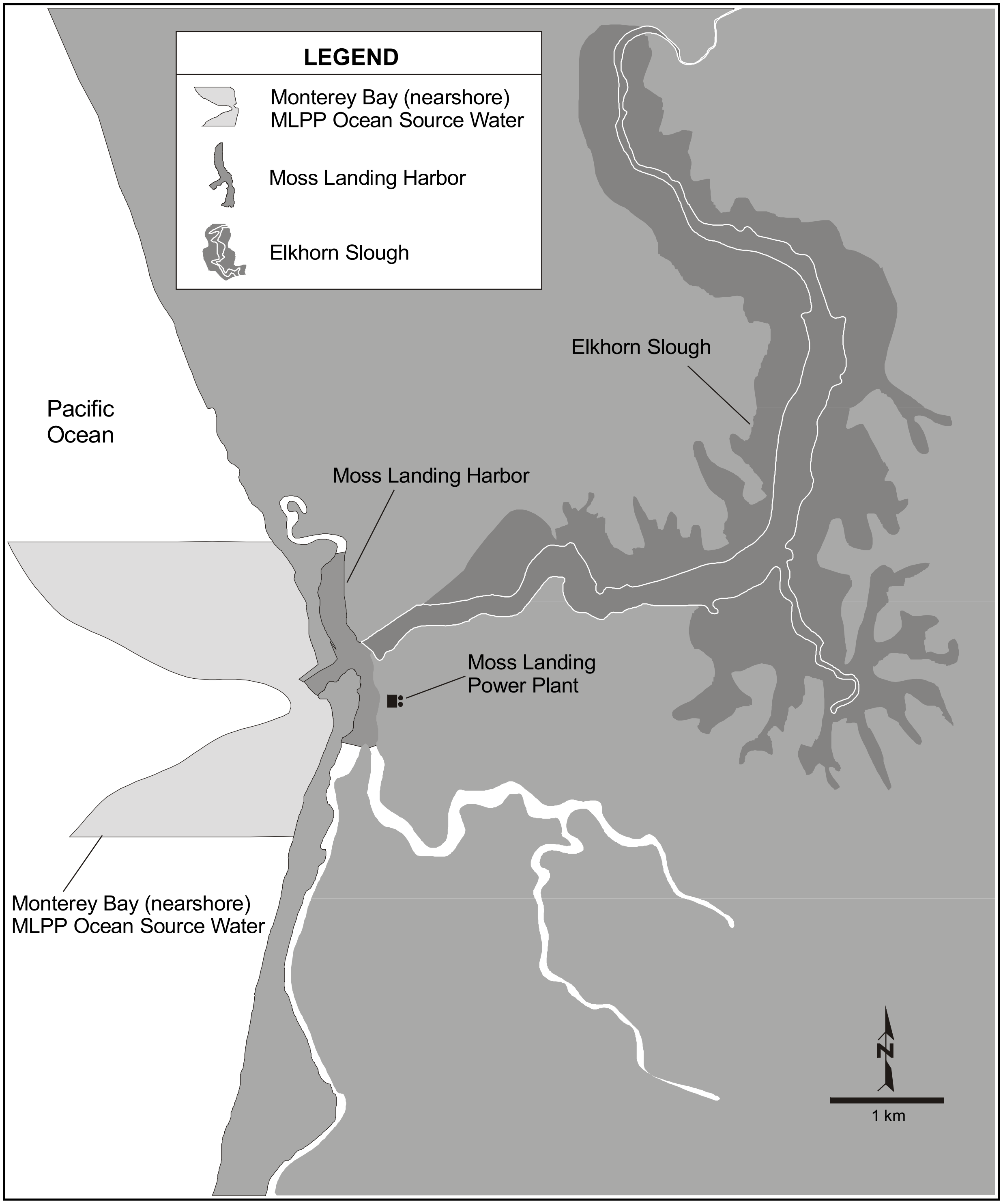


Figure 3-2. Location of Monterey Bay nearshore MLPP ocean source water, Moss Landing Harbor, and Elkhorn Slough areas used in calculating source water and receiving water volumes.

The purpose of the *ETM* calculations is to estimate the probability of mortality of larvae and megalops associated with power plant entrainment. The calculations require not only the abundance of larvae and megalops entrained but also the abundance of the larval and megalopal populations at risk of entrainment. The sampling at the cooling water intakes is used to estimate entrained numbers.

On any one sampling day, the conditional entrainment mortality can be expressed as

$$PE_{ij} = \frac{E_{ij}^{T}}{R_{ij}} \tag{9}$$

where

E_{ij}^{T} = total numbers of larvae entrained on the *j*th day $\left(j = 1, \ldots, d_i\right)$ of the *i*th temporal sampling stratum $(i = 1, \ldots, L)$;

R_{ij} = numbers of larvae at risk of entrainment, i.e., abundance of larvae in Monterey Bay (MB), Moss Landing Harbor (MLH), and Elkhorn Slough (ES).

In turn, the abundance of entrained larvae and megalops can be expressed as the entrainment numbers at the new combined-cycle units intake where

$$E_{ij}^{T} = E_{ij}^{CC} \tag{10}$$

and E_{ij}^{CC} is the entrainment abundance at the new combined-cycle units intake on the *j*th sampling day. With the larval and megalopal source populations *a priori* defined, the abundance of larvae and megalops at risk can then be directly expressed as

$$R_{ij} = V_{MB} \cdot \overline{D}_{MBij} + V_{MLH} \cdot \overline{D}_{MLHij} + V_{ES} \cdot \overline{D}_{ESij} \tag{11}$$

where V denotes the water volume and $\overline{D}$, the average larval and megalopal concentration in a source population during the *ij*th sampling day. Combining Equations (9-11), the probability of entrainment for a larvae and megalop in the three source populations during the *ij*th sampling day can be estimated (Appendix C) by

$$\hat{PE} = \frac{\hat{E}_{ij}^{CC}}{(V_{MB} \cdot \hat{\overline{D}}_{MBij} + V_{MLH} \cdot \hat{\overline{D}}_{MBij} + V_{ES} \cdot \hat{\overline{D}}_{ESij}}$$

$$\hat{P}E = \frac{\hat{E}_{ij}^{CC}}{\left(V_{MB}\cdot\hat{\bar{D}}_{MBij} + V_{MLH}\cdot\hat{\bar{D}}_{MBij} + V_{ES}\cdot\hat{\bar{D}}_{ESij}\right)} \qquad (12)$$

The *ETM* model uses the periodic estimates of PE_{ij} to estimate the annual probability of entrainment mortality (P_M).

How the *ETM* calculations incorporate the individual estimates of PE_{ij} depends on the nature of the entrainment process and on the nature of the spawning and hatching sequence of the fish or crab species. Model formulation will differ whether there is a single synchronous breeding or whether there is multiple overlapping breeding by the species. In the case of a single synchronous breeding within a survey period, the *ETM* can be formulated as

$$\hat{P}_M = 1 - \sum_{i=1}^{L} f_i (1 - PE_i)^{D_i} \qquad (13)$$

where D_i = number of days that larvae or megalops are susceptible to entrainment in the *i*th sampling period and f_i = the fraction of the spawning that occurred during the *i*th sampling period. In Equation (13), the estimated entrainment mortality probability PE_i is assumed to be representative of the daily mortality during the D_i period of time.

In the case where there are multiple non-overlapping spawnings, the *ETM* calculations can be formulated as

$$\hat{P}_M = 1 - \sum_{i=1}^{L}\sum_{j=1}^{d_i} f_{ij} (1 - PE_{ij})^{D_{ij}} \qquad (14)$$

where f_{ij} = fraction of the spawning that occurred during the *ij*th sampling period, D_{ij} = the number of days in the *ij*th sampling period, and d_i are the number of broods in the *i*th sampling period. Equation (14) assumes the population-wide probability of entrainment is the essence of the *ETM* approach of MacCall et al. (1983). If this population is stable and stationary, then $\hat{P}_M$ is also an indicator of the effects on the fully recruited age classes when no compensatory natural mortality is assumed.

4.0 ENTRAINMENT AND SOURCE WATER RESULTS

Larval fish and targeted crab species data presented in this section are from entrainment and source water samples that have had the laboratory processing procedure completed. Entrainment data are from weekly 24-hour surveys conducted from March 2, 1999 through June 30, 1999 and from surveys conducted every other week from July through October 1999. Data from the weekly surveys in November 1999 through February 2000 from the new combined-cycle units intake are also discussed. The remaining samples collected from the Units 6 and 7 intake are currently being processed and the resulting data will be reported in the Final 316(b) demonstration. Data from all monthly source water samples from inception (June 1999) through February 2000 are also presented.

Based on discussions at the January 18, 2000 Technical Working Group meeting, we measured a sub-sample of bay goby *Lepidogobius lepidus* and all longjaw mudsucker *Gillichthys mirabilis* larvae from the following surveys:

- the new combined-cycle units intake entrainment surveys that coincided with monthly source water surveys (June 1999 through January 2000), and

- all source water samples (June 1999 through January 2000).

These length data will be used to estimate the ages of larvae entrained and the larvae available from the source populations. These data are presented in Section 4.4 for bay goby and Section 4.9 for longjaw mudsucker. Both species collected in the February 2000 surveys are currently being measured and the data will be presented in the next report.

4.1 Entrainment Study Results

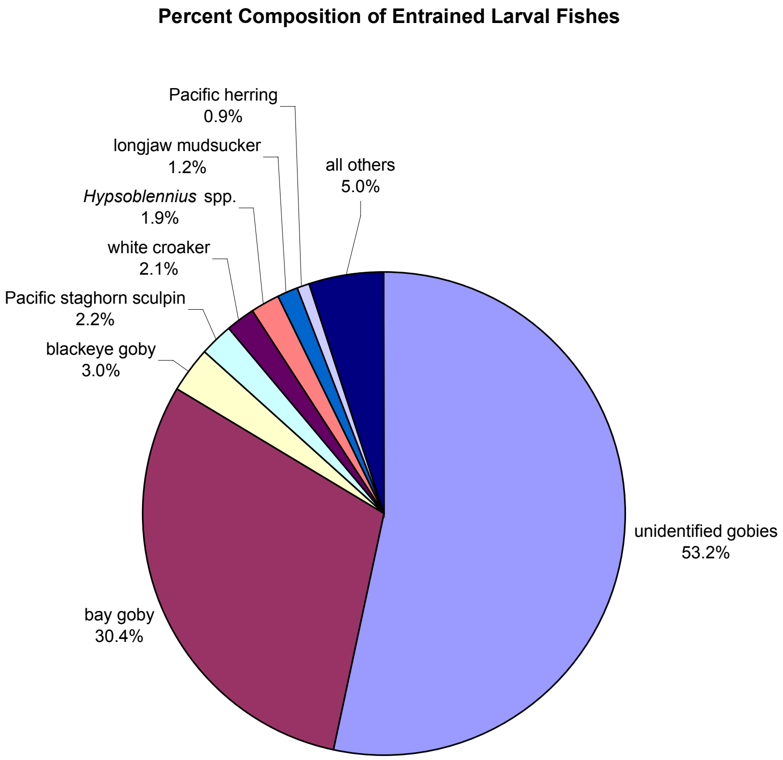
Eight taxa of larval fishes comprised 95 percent of the total numbers of taxa collected in entrainment samples (Figure 4-1a). The taxa, listed in decreasing order of abundance, were: unidentified gobies Gobiidae (53.2 percent), bay goby *Lepidogobius lepidus* (30.4 percent), blackeye goby *Coryphopterus nicholsi* (3.0 percent), Pacific staghorn sculpin *Leptocottus armatus* (2.2 percent), white croaker *Genyonemus lineatus* (2.1 percent), blennies *Hypsoblennius* spp. (1.9 percent), longjaw mudsucker *Gillichthys mirabilis* (1.2 percent), and Pacific herring *Clupea pallasi* (0.9 percent). Of the 95 percent, nearly 88 percent were represented by members of one Family—Gobiidae. This Family included the unidentified gobies, bay goby, blackeye goby, and longjaw mudsucker.

The life histories, range of populations, and habitat descriptions for these taxa are presented in Sections 4-3 through 4-10. Information is presented on the temporal and diurnal concentrations of these taxa collected from in front of the intake of the new combined-cycle units. Mean entrainment concentrations (no./1,000 m^3) for all larval fishes separated by unit groups, for all surveys are presented in Table 4-1. Brief comparisons are made of these current data with the previous 1978 - 1980 entrainment data (PG&E, 1983). The eight taxa listed above are discussed individually in Sections 4.3 through 4.10. Impact assessment analyses for these eight taxa are presented in Section 6.

Six species of Cancridae and one unknown *Cancer* spp. megalops were collected in entrainment samples at the new CC units intake (Figure 4-1b). The species, listed in decreasing order of abundance were: hairy rock crab *Cancer jordani* (29.3 percent), yellow rock crab *Cancer anthonyi* (19.6 percent), brown rock crab *Cancer antennarius* (19.0 percent), dungeness crab *Cancer magister* (14.7 percent), red rock crab *Cancer productus* (9.8 percent), slender rock crab *Cancer gracilis* (7.1 percent), and unidentified *Cancer* spp. (0.5 percent).

The life histories, range of populations, and habitat descriptions for these rock crabs and the European green crab are presented in Sections 4-11 through 4-18. Mean entrainment concentrations (no./1,000 m^3) for all targeted crab species, separated by unit groups, for all surveys are presented in Table 4-1. Impact assessment analyses for all megalopal *Cancer* spp. crabs are presented in Section 6.

(a)



(b)

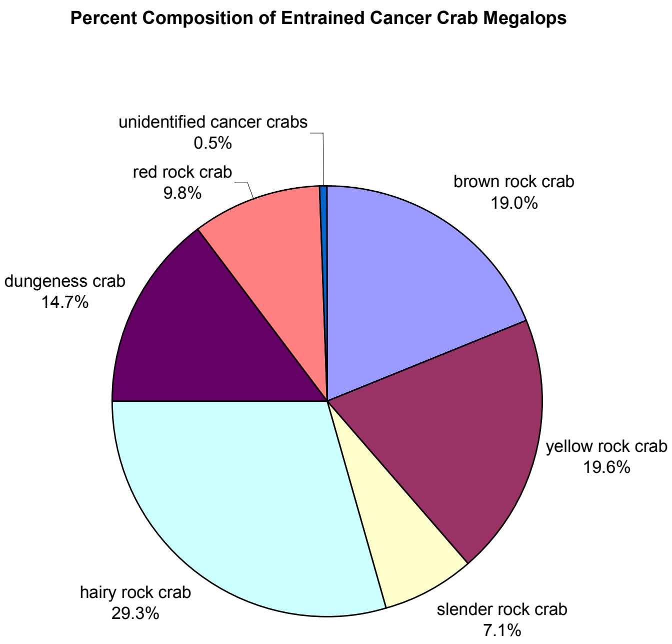


Figure 4-1. a) Percent composition of the most abundant larval fish taxa and b) *Cancer* spp. megalops collected in entrainment surveys at the Moss Landing Power Plant: March 1999 through February 2000.

Table 4-1. Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa and Megalops of *Cancer* spp. and European Green Crabs Collected in front of the Moss Landing Power Plant New Combined-cycle Units and Units 6 and 7 Intakes: March 2, 1999 through February 24, 2000.

Taxon	Common Name	Count	Survey 1 March 2-3, 1999				Survey 2 March 8-9, 1999				Survey 3 March 14-15, 1999				Survey 4 March 22-23, 1999				Survey 5 March 30-31, 1999			
			New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12	
			Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.
Ammodytes hexapterus	Pacific sand lance	191	3	3.2	1	0.8	1	1.7			2	2.8										
Artedius lateralis	smoothhead sculpin	4	1	1.2	2	3.1																
Artedius spp.	sculpins	35	3	4.2			1	1.2	8	12.9	2	3.1	2	3.8			2	3.9				
Atherinidae unid.	silversides	94																			1	1.5
Atherinops affinis	topsmelt	19																				
Atherinopsis californiensis	jacksmelt	349	20	26.1	9	13.0	5	6.9	4	6.4	6	8.5	1	2.2					4	5.2		
Aulorhynchus flavidus	tubesnout	2																				
Bathylagus ochotensis	popeye blacksmelt	1																				
Bathymasteridae unid.	ronquils	1					1	1.5														
Blennioidei	blennies	3																				
Brosmophycis marginata	red brotula	1																				
Cebidichthys violaceus	monkeyface eel	195	3	3.6	3	4.5					4	5.6					2	3.5	1	1.2		
Chaenopsidae unid.	tube blennies	19																				
Citharichthys sordidus	Pacific sanddab	8																				
Citharichthys stigmaeus	speckled sanddab	12																				
Clinocottus analis	wooly sculpin	9																				
Clupea pallasii	Pacific herring	830	7	9.3	7	10.8	3	3.8	6	9.8	10	14.0	46	78.8	7	10.3	30	57.6	9	13.4	4	6.6
Clupeidae unid.	herrings	14															1	2.1				
Clupeiformes	herrings and anchovies	15																				
Coryphopterus nicholsi	blackeye goby	1,637	1	1.2			11	15.9	2	3.6	4	6.4	1	1.7	8	11.8	8	12.3	10	15.3	13	22.3
Cottidae unid.	sculpins	124	2	2.6	3	3.2	4	5.9	7	11.8					1	1.5					1	1.7
Cottus asper	prickly sculpin	234	9	11.0	29	42.4	3	4.1	7	11.5	3	4.0	39	80.3	1	1.6	7	12.6	1	1.7	4	6.9
Engraulis mordax	northern anchovy	223																				
Genyonemus lineatus	white croaker	1,101	7	8.3	2	3.1	143	196.5	103	167.4	1	1.3							1	1.5		
Gibbonsia spp.	clinid kelpfishes	17																				
Gillichthys mirabilis	longjaw mudsucker	882	15	19.7	13	19.7	1	1.5	3	5.3	5	7.6	7	13.1	7	10.3	7	13.0	8	13.2	14	26.7
Gobiesocidae unid.	clingfishes	1					1	1.2														
Gobiesox spp.	clingfishes	2	1	1.6																		
Gobiidae - type I	gobies	2																				
Gobiidae unid.	gobies	29,211	599	741.8	442	651.0	182	262.9	142	248.6	629	959.1	345	618.5	244	371.7	197	360.8	448	689.2	498	861.4
Hexagrammidae unid.	greenlings	2													1	1.7						
Hypsoblennius spp.	blennies	1,163																				
larval fish - damaged	unidentified larval fishes	67																				
larval fish fragment	unidentified larval fishes	274	4	4.5	3	5.2					3	4.5	1	1.8	1	1.4	1	1.9	1	1.2	1	1.3
larval/post-larval fish, unid.	unidentified larval fishes	29	1	1.6	1	1.5			1	1.7	3	4.0			6	9.3	2	2.9				
Lepidogobius lepidus	bay goby	14,337	145	185.9	32	37.6	67	93.4	44	76.6	112	159.2	28	48.3	48	73.0	25	44.1	74	111.4	24	44.6
Leptocottus armatus	Pacific staghorn sculpin	1,431	33	42.3	27	41.7	24	36.0	18	29.4	28	40.1	15	23.9	4	5.9	1	1.6	17	24.3	10	18.4
Leuroglossus stilbius	California smoothtongue	1																				
Liparis fucensis	slipskin snailfish	1																			1	1.5
Liparis spp.	snailfishes	6																				
Oligocottus spp.	sculpins	24																				
Ophidiidae unid.	cusk-eels	1																				
Ophiodon elongatus	lingcod	1																				
Osmeridae unid.	smelts	391	5	7.3	5	7.8	4	5.2	2	3.8	2	2.4					1	1.4	7	10.0	16	27.9
Oxylebius pictus	painted greenling	10									2	2.9							1	1.5		
Parophrys vetulus	English sole	14					7	9.5	1	1.7	2	3.0										
Pholididae unid.	gunnels	3											1	1.6								
Pleuronectes bilineatus	rock sole	11																				
Pleuronectes isolepis	butter sole	2																				
Pleuronectidae unid.	flounders	58			1	1.5			1	1.4												
Pleuronectiformes unid.	flatfishes	28			1	1.7	1	1.9														
Psettichthys melanostictus	sand sole	4			1	1.3																
Ruscarius creaseri	rouchcheek sculpin	5																				
Sardinops sagax	Pacific sardine	3																				
Scorpaenichthys marmoratus	cabezon	5																				
Sebastes spp.	rockfishes	2																				
Sebastes spp. V	rockfishes	18	1	1.6																		
Sebastes spp. V_D	rockfishes	2																				
Sebastes spp. V_De	rockfishes	29	4	6.3									1	1.7							2	3.6
Sebastes spp. VD	rockfishes	3																				
Sebastes spp. VP	rockfishes	1									1	1.1										
Sebastolobus spp.	thornyheads	74																				
Stenobrachius leucopsarus	northern lampfish	340	1	1.2	1	1.5	3	4.3	3	4.8					8	11.1	7	11.2				
Stichaeidae unid.	pricklebacks	7					1	1.2			1	1.3										
Syngnathidae unid.	pipefishes	4																				
Syngnathus spp.	pipefishes	5																				
Tarletonbeania crenularis	blue lanternfish	25																				
Typhlogobius californiensis	blind goby	1																				
	FISH TOTALS:	53,618	865		583		463		352		820		487		336		291		582		589	
Cancer antennarius (megalops)	brown rock crab	47									1	1.3										
Cancer anthonyi (megalops)	yellow rock crab	55																				
Cancer gracilis (megalops)	slender rock crab	25									1	1.3										
Cancer jordani (megalops)	hairy rock crab	124																				
Cancer magister (megalops)	dungeness crab	37																				
Cancer productus (megalops)	red rock crab	28					1	1.4									1	1.8	1	1.5		
Cancer spp. (megalops)	unidentified cancer crabs	5																				
Carcinus maenas (megalops)	European green crab	5																				
	CRAB TOTALS:	326	0		0		1		0		2		0		0		1		1		0	

Table 4-1. (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa and Megalops of *Cancer* spp. and European Green Crabs Collected in front of the Moss Landing Power Plant New Combined-cycle Units and Units 6 and 7 Intakes: March 2, 1999 through February 24, 2000.

Taxon	Common Name	Survey 6 April 4-5, 1999				Survey 7 April 15-16, 1999				Survey 8 April 22-23, 1999				Survey 9 April 23-30, 1999				Survey 10 May 6-7, 1999			
		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12	
		Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.
Ammodytes hexapterus	Pacific sand lance																				
Artedius lateralis	smoothhead sculpin									1	1.4										
Artedius spp.	sculpins			1	1.5							2	3.2					1	1.3	1	1.9
Atherinidae unid.	silversides																				
Atherinops affinis	topsmelt																			1	1.6
Atherinopsis californiensis	jacksmelt	3	4.2	4	6.4					3	4.3	2	3.1								
Aulorhynchus flavidus	tubesnout											1	1.7								
Bathylagus ochotensis	popeye blacksmelt																				
Bathymasteridae unid.	ronquils																				
Blennioidei	blennies																				
Brosmophycis marginata	red brotula													1	1.4						
Cebidichthys violaceus	monkeyface eel	12	17.3	42	73.8					8	10.8	2	3.5					38	63.8	5	8.7
Chaenopsidae unid.	tube blennies			1	1.1			1	1.8												
Citharichthys sordidus	Pacific sanddab																				
Citharichthys stigmaeus	speckled sanddab																				
Clinocottus analis	wooly sculpin													1	1.4						
Clupea pallasii	Pacific herring	4	6.6	7	10.4	12	16.1	19	30.6	54	79.7	39	67.3	24	39.1	31	52.7	2	3.7	8	13.8
Clupeidae unid.	herrings					1	1.4	2	3.5	2	2.9	1	2.0								
Clupeiformes	herrings and anchovies											4	6.7								
Coryphopterus nicholsi	blackeye goby	18	25.9	18	29.7	11	14.6	8	12.6	35	47.4	24	40.2	2	3.0	14	23.7	56	95.5	20	37.0
Cottidae unid.	sculpins			2	2.6	1	1.9			1	1.4									1	1.9
Cottus asper	prickly sculpin	6	9.4	7	11.2	6	8.4	5	8.6	1	1.1	2	3.4			3	4.6				
Engraulis mordax	northern anchovy					1	1.4	1	1.8												
Genyonemus lineatus	white croaker	1	1.6																		
Gibbonsia spp.	clinid kelpfishes			1	1.5																
Gillichthys mirabilis	longjaw mudsucker	10	17.0	5	7.5	8	10.7	11	17.0	6	9.1	3	5.4	3	4.7	9	15.3	6	11.2	2	4.1
Gobiesocidae unid.	clingfishes																				
Gobiesox spp.	clingfishes							1	1.3												
Gobiidae - type I	gobies																				
Gobiidae unid.	gobies	489	722.8	303	494.3	419	572.7	331	526.3	497	717.9	259	459.7	286	414.2	219	378.1	509	872.6	274	498.3
Hexagrammidae unid.	greenlings																				
Hypsoblennius spp.	blennies													1	1.1						
larval fish - damaged	unidentified larval fishes																				
larval fish fragment	unidentified larval fishes	1	1.2	2	2.8	4	5.1					1	1.7			1	1.8	1	1.9	1	1.9
larval/post-larval fish, unid.	unidentified larval fishes																				
Lepidogobius lepidus	bay goby	401	485.5	23	36.7	30	41.0	5	7.6	165	229.8	49	86.6	54	75.1	25	36.9	15	22.3	7	12.3
Leptocottus armatus	Pacific staghorn sculpin	5	6.9	9	13.5	3	4.1	5	7.6	6	8.3	1	1.9			1	1.9	2	3.2	2	4.2
Leuroglossus stilbius	California smoothtongue																				
Liparis fucensis	slipskin snailfish																				
Liparis spp.	snailfishes																	1	1.6		
Oligocottus spp.	sculpins																				
Ophidiidae unid.	cusk-eels																				
Ophiodon elongatus	lingcod																				
Osmeridae unid.	smelts	8	9.4	5	6.8	42	58.0	38	60.7	2	2.6	1	1.6	3	4.2	10	16.9			1	2.3
Oxylebius pictus	painted greenling	2	3.4															1	1.3		
Parophrys vetulus	English sole																				
Pholididae unid.	gunnels																				
Pleuronectes bilineatus	rock sole																				
Pleuronectes isolepis	butter sole																				
Pleuronectidae unid.	flounders											1	1.6								
Pleuronectiformes unid.	flatfishes					1	1.4														
Psettichthys melanostictus	sand sole																				
Ruscarius creaseri	rouchcheek sculpin	1	1.7	1	1.9							1	1.5							1	1.9
Sardinops sagax	Pacific sardine																				
Scorpaenichthys marmoratus	cabezon																				
Sebastes spp.	rockfishes																				
Sebastes spp. V	rockfishes																				
Sebastes spp. V_D	rockfishes																	1	1.9		
Sebastes spp. V_De	rockfishes	3	4.7					2	3.7									5	8.3		
Sebastes spp. VD	rockfishes																				
Sebastes spp. VP	rockfishes																				
Sebastolobus spp.	thornyheads																				
Stenobrachius leucopsarus	northern lampfish															1	1.4				
Stichaeidae unid.	pricklebacks																				
Syngnathidae unid.	pipefishes																				
Syngnathus spp.	pipefishes																				
Tarletonbeania crenularis	blue lanternfish																				
Typhlogobius californiensis	blind goby																				
	FISH TOTALS:	964		431		539		429		781		393		375		314		638		324	
Cancer antennarius (megalops)	brown rock crab	1	1.6																		
Cancer anthonyi (megalops)	yellow rock crab																				
Cancer gracilis (megalops)	slender rock crab																				
Cancer jordani (megalops)	hairy rock crab																				
Cancer magister (megalops)	dungeness crab					2	2.7	1	1.6	6	7.8	2	3.4	1	1.2			2	2.7	4	6.7
Cancer productus (megalops)	red rock crab																				
Cancer spp. (megalops)	unidentified cancer crabs																				
Carcinus maenas (megalops)	European green crab					2	2.8			1	1.2					1	1.6				
	CRAB TOTALS:	1		0		4		1		7		2		1		1		2		4	

Table 4-1. (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa, Megalops of *Cancer* spp. and European Green Crabs Collected in front of the Moss Landing Power Plant New Combined-cycle Units and Units 6 and 7 Intakes: March 2, 1999 through February 24, 2000.

Taxon	Common Name	Survey 11 May 13-14, 1999				Survey 12 May 20-21, 1999				Survey 13 May 27-28, 1999				Survey 14 June 3-4, 1999				Survey 15 June 10-11, 1999			
		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12	
		Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.
Ammodytes hexapterus	Pacific sand lance																				
Artedius lateralis	smoothhead sculpin																				
Artedius spp.	sculpins	1	1.4			1	1.6	1	1.5	1	1.7	2	3.4							1	1.6
Atherinidae unid.	silversides			1	1.5	1	1.6			1	1.3			2	2.5	1	1.5	2	3.0		
Atherinops affinis	topsmelt	1	1.5			1	1.6	1	1.6							1	1.3	2	2.9		
Atherinopsis californiensis	jacksmelt																				
Aulorhynchus flavidus	tubesnout																				
Bathylagus ochotensis	popeye blacksmelt																				
Bathymasteridae unid.	ronquils																				
Blennioidei	blennies																				
Brosmophycis marginata	red brotula																				
Cebidichthys violaceus	monkeyface eel			1	1.3	12	16.5	2	3.0	29	34.1			9	11.2					1	1.7
Chaenopsidae unid.	tube blennies																				
Citharichthys sordidus	Pacific sanddab																				
Citharichthys stigmaeus	speckled sanddab																				
Clinocottus analis	wooly sculpin																				
Clupea pallasii	Pacific herring	6	8.6	19	27.2	1	1.6	12	18.4	2	2.7	17	24.9	6	9.1	12	20.6	7	9.4	10	15.0
Clupeidae unid.	herrings			2	2.5			2	3.1												
Clupeiformes	herrings and anchovies																				
Coryphopterus nicholsi	blackeye goby	10	14.5	1	1.3	71	99.2	153	230.5	13	18.3	3	4.5	51	65.2	17	25.4	59	77.3	33	49.0
Cottidae unid.	sculpins			1	1.8	1	1.6			1	1.2			1	1.5						
Cottus asper	prickly sculpin			1	1.5							1	1.6								
Engraulis mordax	northern anchovy																				
Genyonemus lineatus	white croaker																				
Gibbonsia spp.	clinid kelpfishes					1	1.6	1	1.5					3	3.7	2	2.9			1	2.1
Gillichthys mirabilis	longjaw mudsucker	9	12.2	2	3.0	6	8.8	14	21.1	4	5.9	6	9.0	10	14.4	13	19.2	22	34.7	21	42.3
Gobiesocidae unid.	clingfishes																				
Gobiesox spp.	clingfishes																				
Gobiidae - type I	gobies																	2	2.4		
Gobiidae unid.	gobies	556	757.5	218	323.8	180	248.7	125	185.8	404	563.7	134	211.2	649	845.3	221	341.3	783	1164.6	290	550.0
Hexagrammidae unid.	greenlings	1	1.2																		
Hypsoblennius spp.	blennies	1	1.6			3	4.8	4	5.6	2	3.1	1	1.6	5	7.6	6	9.2	12	17.3	6	10.1
larval fish - damaged	unidentified larval fishes															1	1.8				
larval fish fragment	unidentified larval fishes	4	5.1			3	4.1	1	1.4			2	2.7					2	3.2		
larval/post-larval fish, unid.	unidentified larval fishes																	4	6.8		
Lepidogobius lepidus	bay goby	27	34.9	21	32.5	31	41.6	44	65.9	31	43.0	21	33.6	84	109.9	11	15.6	69	85.9	14	21.7
Leptocottus armatus	Pacific staghorn sculpin	5	6.4	2	2.5	1	1.3									1	1.5				
Leuroglossus stilbius	California smoothtongue	1	1.1																		
Liparis fucensis	slipskin snailfish																				
Liparis spp.	snailfishes																				
Oligocottus spp.	sculpins																			1	1.7
Ophidiidae unid.	cusk-eels																				
Ophiodon elongatus	lingcod																				
Osmeridae unid.	smelts	4	4.7	1	1.2	1	1.3	3	4.6	6	7.3	9	13.0	4	5.5	1	1.3			1	1.8
Oxylebius pictus	painted greenling													1	1.3						
Parophrys vetulus	English sole																				
Pholididae unid.	gunnels																				
Pleuronectes bilineatus	rock sole																				
Pleuronectes isolepis	butter sole																				
Pleuronectidae unid.	flounders																				
Pleuronectiformes unid.	flatfishes																				
Psettichthys melanostictus	sand sole																				
Ruscarius creaseri	rouchcheek sculpin																				
Sardinops sagax	Pacific sardine																				
Scorpaenichthys marmoratus	cabezon																				
Sebastes spp.	rockfishes																				
Sebastes spp. V	rockfishes																				
Sebastes spp. V_D	rockfishes																				
Sebastes spp. V_De	rockfishes	6	7.0			2	2.9	1	1.3					1	1.5						
Sebastes spp. VD	rockfishes	1	1.1																		
Sebastes spp. VP	rockfishes																				
Sebastolobus spp.	thornyheads																				
Stenobrachius leucopsarus	northern lampfish																				
Stichaeidae unid.	pricklebacks																				
Syngnathidae unid.	pipefishes															1	1.5				
Syngnathus spp.	pipefishes																				
Tarletonbeania crenularis	blue lanternfish																				
Typhlogobius californiensis	blind goby																				
	FISH TOTALS:	633		270		316		364		494		196		826		288		964		379	
Cancer antennarius (megalops)	brown rock crab																				
Cancer anthonyi (megalops)	yellow rock crab																				
Cancer gracilis (megalops)	slender rock crab																				
Cancer jordani (megalops)	hairy rock crab																				
Cancer magister (megalops)	dungeness crab	2	2.3			8	10.1			1	1.2	1	1.3	5	6.3	2	2.7				
Cancer productus (megalops)	red rock crab					7	8.3							1	1.2						
Cancer spp. (megalops)	unidentified cancer crabs																				
Carcinus maenas (megalops)	European green crab																				
	CRAB TOTALS:	2		0		15		0		1		1		6		2		0		0	

Table 4-1. (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa and Megalops of *Cancer* spp. and European Green Crabs Collected in front of the Moss Landing Power Plant New Combined-cycle Units and Units 6 and 7 Intakes: March 2, 1999 through February 24, 2000.

Taxon	Common Name	Survey 16 June 17-18, 1999				Survey 17 June 24-25, 1999				Survey 18 July 12-13, 1999				Survey 19 July 29-30, 1999				Survey 20 August 12-13, 1999			
		New CC Units N = 11*		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12	
		Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.
Ammodytes hexapterus	Pacific sand lance																				
Artedius lateralis	smoothhead sculpin																				
Artedius spp.	sculpins							2	3.1												
Atherinidae unid.	silversides									9	10.0	2	3.1	1	1.6	1	1.5	1	1.4		
Atherinops affinis	topsmelt			1	1.3	1	1.2					1	2.5			1	1.8				
Atherinopsis californiensis	jacksmelt													2	3.3						
Aulorhynchus flavidus	tubesnout																				
Bathylagus ochotensis	popeye blacksmelt																				
Bathymasteridae unid.	ronquils																				
Blennioidei	blennies																				
Brosmophycis marginata	red brotula																				
Cebidichthys violaceus	monkeyface eel																				
Chaenopsidae unid.	tube blennies															1	1.3				
Citharichthys sordidus	Pacific sanddab																				
Citharichthys stigmaeus	speckled sanddab																				
Clinocottus analis	wooly sculpin																				
Clupea pallasii	Pacific herring	7	12.3	5	9.3	6	8.3	1	1.4			2	3.0							2	2.9
Clupeidae unid.	herrings																				
Clupeiformes	herrings and anchovies																				
Coryphopterus nicholsi	blackeye goby	42	63.3	12	19.4	42	57.3	15	22.2	23	26.9	7	12.9	12	21.0	15	25.0	3	4.9	13	18.5
Cottidae unid.	sculpins							1	1.3			1	1.5								
Cottus asper	prickly sculpin																				
Engraulis mordax	northern anchovy																				
Genyonemus lineatus	white croaker					2	2.4														
Gibbonsia spp.	clinid kelpfishes	1	1.0																		
Gillichthys mirabilis	longjaw mudsucker	1	1.8	4	6.5	16	20.4	14	17.2	6	9.3	7	13.0	6	11.2	14	20.9	6	10.7	10	14.7
Gobiesocidae unid.	clingfishes																				
Gobiesox spp.	clingfishes																				
Gobiidae - type I	gobies																				
Gobiidae unid.	gobies	231	313.9	104	174.2	694	892.7	321	426.4	88	141.4	127	238.7	97	177.3	247	417.3	27	42.8	136	193.4
Hexagrammidae unid.	greenlings																				
Hypsoblennius spp.	blennies	17	25.0	6	10.3	20	26.7	7	9.8	32	42.2	25	39.8	50	85.1	44	66.8	42	69.2	103	142.1
larval fish - damaged	unidentified larval fishes					4	5.2	2	3.0							2	3.6				
larval fish fragment	unidentified larval fishes			1	1.2	5	6.8	3	4.4	2	3.3			2	3.4			1	1.6		
larval/post-larval fish, unid.	unidentified larval fishes					1	1.4					1	1.7	1	1.7	2	2.8				
Lepidogobius lepidus	bay goby	80	93.8	27	38.9	162	210.6	57	78.8	61	68.6	8	12.5	58	103.5	78	108.2	66	99.7	13	21.1
Leptocottus armatus	Pacific staghorn sculpin					1	1.3									1	1.7				
Leuroglossus stilbius	California smoothtongue																				
Liparis fucensis	slipskin snailfish																				
Liparis spp.	snailfishes	1	1.6							1	1.0										
Oligocottus spp.	sculpins																				
Ophidiidae unid.	cusk-eels																				
Ophiodon elongatus	lingcod																				
Osmeridae unid.	smelts	5	6.6	2	3.2	4	5.1	6	8.1									1	1.4		
Oxylebius pictus	painted greenling					1	1.4									1	1.3				
Parophrys vetulus	English sole																				
Pholididae unid.	gunnels																				
Pleuronectes bilineatus	rock sole																				
Pleuronectes isolepis	butter sole																				
Pleuronectidae unid.	flounders																				
Pleuronectiformes unid.	flatfishes																				
Psettichthys melanostictus	sand sole																				
Ruscarius creaseri	rouchcheek sculpin					1	1.2														
Sardinops sagax	Pacific sardine																				
Scorpaenichthys marmoratus	cabezon																				
Sebastes spp.	rockfishes																				
Sebastes spp. V	rockfishes																				
Sebastes spp. V_D	rockfishes	1	1.3																		
Sebastes spp. V_De	rockfishes																				
Sebastes spp. VD	rockfishes																				
Sebastes spp. VP	rockfishes																				
Sebastolobus spp.	thornyheads																				
Stenobrachius leucopsarus	northern lampfish																				
Stichaeidae unid.	pricklebacks																				
Syngnathidae unid.	pipefishes													1	1.6						
Syngnathus spp.	pipefishes																				
Tarletonbeania crenularis	blue lanternfish																				
Typhlogobius californiensis	blind goby																				
	FISH TOTALS:	386		162		960		429		222		181		230		407		147		277	
Cancer antennarius (megalops)	brown rock crab																	1	1.1		
Cancer anthonyi (megalops)	yellow rock crab																				
Cancer gracilis (megalops)	slender rock crab																				
Cancer jordani (megalops)	hairy rock crab											1	1.7							1	1.5
Cancer magister (megalops)	dungeness crab																				
Cancer productus (megalops)	red rock crab			1	1.3					1	1.0										
Cancer spp. (megalops)	unidentified cancer crabs																			1	1.2
Carcinus maenas (megalops)	European green crab																				
	CRAB TOTALS:	0		1		0		0		1		1		0		0		1		2	

*One sample voided during laboratory processing.

Table 4-1. (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa and Megalops of *Cancer* spp. and European Green Crabs Collected in front of the Moss Landing Power Plant New Combined-cycle Units and Units 6 and 7 Intakes: March 2, 1999 through February 24, 2000.

Taxon	Common Name	Survey 21				Survey 22				Survey 23				Survey 24				Survey 25			
		Aug. 31 - Sep. 1, 1999				September 16-17, 1999				Sep. 30 - Oct. 1, 1999				October 14 - 15, 1999				October 28 - 29, 1999			
		New CC Units		Units 6&7		New CC Units		Units 6&7		New CC Units		Units 6&7		New CC Units		Units 6&7		New CC Units		Units 6&7	
		N = 12		N = 12		N = 12		N = 12		N = 12		N = 12		N = 12		N = 12		N = 12		N = 12	
		Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.
Ammodytes hexapterus	Pacific sand lance																				
Artedius lateralis	smoothhead sculpin																				
Artedius spp.	sculpins															1	2.6				
Atherinidae unid.	silversides	14	20.7	5	8.8																
Atherinops affinis	topsmelt			8	11.0																
Atherinopsis californiensis	jacksmelt			1	1.5															2	2.6
Aulorhynchus flavidus	tubesnout																				
Bathylagus ochotensis	popeye blacksmelt																				
Bathymasteridae unid.	ronquils																				
Blennioidei	blennies											2	2.9								
Brosmophycis marginata	red brotula																				
Cebidichthys violaceus	monkeyface eel																				
Chaenopsidae unid.	tube blennies			1	1.2	8	12.1	2	2.7	2	3.4	2	2.9								
Citharichthys sordidus	Pacific sanddab																				
Citharichthys stigmaeus	speckled sanddab																				
Clinocottus analis	wooly sculpin			1	1.4	1	1.5							2	3.3			1	1.7		
Clupea pallasii	Pacific herring	1	1.5	2	3.1			1	1.2									5	8.2	8	11.9
Clupeidae unid.	herrings																				
Clupeiformes	herrings and anchovies	1	1.4																		
Coryphopterus nicholsi	blackeye goby	64	88.8	40	57.5	75	111.2	57	77.1	17	28.4	4	5.8	59	89.4	91	128.1	20	33.1	10	15.4
Cottidae unid.	sculpins															2	2.6	1	1.8		
Cottus asper	prickly sculpin																				
Engraulis mordax	northern anchovy					1	1.4			1	1.5									2	2.9
Genyonemus lineatus	white croaker											1	1.9								
Gibbonsia spp.	clinid kelpfishes											1	1.0								
Gillichthys mirabilis	longjaw mudsucker	7	10.3	2	3.3	7	10.3	14	19.5	7	11.8	6	8.9	18	27.3	7	8.7	19	32.5	17	27.0
Gobiesocidae unid.	clingfishes																				
Gobiesox spp.	clingfishes																				
Gobiidae - type I	gobies																				
Gobiidae unid.	gobies	111	159.3	140	195.6	294	438.0	422	578.4	107	179.9	171	252.1	277	428.6	405	524.8	186	308.9	182	272.7
Hexagrammidae unid.	greenlings																				
Hypsoblennius spp.	blennies	145	210.1	118	172.1	182	270.8	154	211.4	22	37.2	20	29.8	39	60.7	33	42.5	13	20.8	9	14.3
larval fish - damaged	unidentified larval fishes											1	1.4								
larval fish fragment	unidentified larval fishes	1	1.4	3	4.0	1	1.6	2	2.6	2	3.4	2	2.9			4	5.4	2	2.7		
larval/post-larval fish, unid.	unidentified larval fishes																				
Lepidogobius lepidus	bay goby	143	164.6	55	74.9	192	277.1	176	241.2	118	206.6	97	144.3	163	234.8	194	226.2	345	471.5	215	331.0
Leptocottus armatus	Pacific staghorn sculpin	3	4.4	1	1.4									4	6.4	2	2.3	3	4.6	5	6.7
Leuroglossus stilbius	California smoothtongue																				
Liparis fucensis	slipskin snailfish																				
Liparis spp.	snailfishes																				
Oligocottus spp.	sculpins																				
Ophidiidae unid.	cusk-eels																				
Ophiodon elongatus	lingcod																				
Osmeridae unid.	smelts	2	2.9			1	1.5	2	2.3												
Oxylebius pictus	painted greenling																				
Parophrys vetulus	English sole																				
Pholididae unid.	gunnels																				
Pleuronectes bilineatus	rock sole																				
Pleuronectes isolepis	butter sole																				
Pleuronectidae unid.	flounders															1	2.6				
Pleuronectiformes unid.	flatfishes																				
Psettichthys melanostictus	sand sole																				
Ruscarius creaseri	rouchcheek sculpin																				
Sardinops sagax	Pacific sardine																				
Scorpaenichthys marmoratus	cabezon																				
Sebastes spp.	rockfishes																				
Sebastes spp. V	rockfishes																				
Sebastes spp. V_D	rockfishes																				
Sebastes spp. V_De	rockfishes																				
Sebastes spp. VD	rockfishes																				
Sebastes spp. VP	rockfishes																				
Sebastolobus spp.	thornyheads																				
Stenobrachius leucopsarus	northern lampfish																				
Stichaeidae unid.	pricklebacks	1	1.4					1	1.2												
Syngnathidae unid.	pipefishes	1	1.0																		
Syngnathus spp.	pipefishes					2	2.9														
Tarletonbeania crenularis	blue lanternfish																				
Typhlogobius californiensis	blind goby																				
	FISH TOTALS:	494		377		764		831		276		307		562		740		595		450	
Cancer antennarius (megalops)	brown rock crab					6	9.1			5	9.2	6	10.8	3	4.1						
Cancer anthonyi (megalops)	yellow rock crab																				
Cancer gracilis (megalops)	slender rock crab											5	8.9								
Cancer jordani (megalops)	hairy rock crab	2	2.9	4	6.3	7	10.5			32	63.0	54	101.1	5	6.9	4	5.0				
Cancer magister (megalops)	dungeness crab																				
Cancer productus (megalops)	red rock crab																				
Cancer spp. (megalops)	unidentified cancer crabs									1	2.2	1	1.9								
Carcinus maenas (megalops)	European green crab																				
	CRAB TOTALS:	2		4		13		0		38		66		8		4		0		0	

Table 4-1. (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa and Megalops of *Cancer* spp. and European Green Crabs Collected in front of the Moss Landing Power Plant New Combined-cycle Units and Units 6 and 7 Intakes: March 2, 1999 through February 24, 2000.

Taxon	Common Name	Survey 26 November 4 - 5, 1999				Survey 27 November 11 - 12, 1999				Survey 28 November 18 - 19, 1999				Survey 29 November 22 - 23, 1999				Survey 30 December 2 - 3, 1999			
		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12	
		Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.
Ammodytes hexapterus	Pacific sand lance																				
Artedius lateralis	smoothhead sculpin																				
Artedius spp.	sculpins																				
Atherinidae unid.	silversides	2	2.9	1	1.1			1	1.2	4	4.8					10	15.9	15	22.2	14	16.5
Atherinops affinis	topsmelt																				
Atherinopsis californiensis	jacksmelt	1	1.4							1	1.4			3	5.8	12	20.4	41	55.6	30	34.9
Aulorhynchus flavidus	tubesnout																				
Bathylagus ochotensis	popeye blacksmelt																				
Bathymasteridae unid.	ronquils																				
Blennioidei	blennies	1	1.2																		
Brosmophycis marginata	red brotula																				
Cebidichthys violaceus	monkeyface eel																				
Chaenopsidae unid.	tube blennies																				
Citharichthys sordidus	Pacific sanddab																				
Citharichthys stigmaeus	speckled sanddab																				
Clinocottus analis	wooly sculpin	1	1.6																		
Clupea pallasii	Pacific herring			2	2.7							1	1.7					1	1.5	3	3.7
Clupeidae unid.	herrings																				
Clupeiformes	herrings and anchovies	1	1.4	1	1.3																
Coryphopterus nicholsi	blackeye goby	20	28.0	16	21.0	170	280.8	26	36.1	12	18.1	2	2.4	4	7.6	1	1.8	12	17.0	10	9.8
Cottidae unid.	sculpins	2	2.6			1	1.9			4	6.0					2	3.2			3	3.6
Cottus asper	prickly sculpin																				
Engraulis mordax	northern anchovy	6	8.6	6	7.6	8	13.6	13	18.6	7	9.4	3	5.2	6	9.8	14	25.8	5	7.0	13	15.5
Genyonemus lineatus	white croaker	1	1.2							4	6.1			8	14.3	6	10.9	20	28.8	5	5.8
Gibbonsia spp.	clinid kelpfishes																	1	1.5		
Gillichthys mirabilis	longjaw mudsucker	30	43.1	27	35.5	18	28.4	26	38.5	13	18.9	12	16.8	13	24.4	31	53.5	9	12.4	25	28.6
Gobiesocidae unid.	clingfishes																				
Gobiesox spp.	clingfishes																				
Gobiidae - type I	gobies																				
Gobiidae unid.	gobies	1,305	1798.7	772	1018.9	493	788.5	482	719.4	568	851.5	344	488.3	208	369.5	445	749.5	390	545.0	663	745.5
Hexagrammidae unid.	greenlings																				
Hypsoblennius spp.	blennies	8	12.0	6	8.2	12	19.7	1	1.2	6	8.8	2	3.1	1	1.9	1	1.4	1	1.5	1	1.1
larval fish - damaged	unidentified larval fishes																	5	7.6	6	6.6
larval fish fragment	unidentified larval fishes	6	8.8	3	3.9	1	1.5	3	4.3	5	8.3	2	2.7	1	1.8	12	19.4	8	11.7	13	15.6
larval/post-larval fish, unid.	unidentified larval fishes																				
Lepidogobius lepidus	bay goby	457	655.2	142	188.9	609	1080.8	495	698.4	1,689	2668.2	248	382.4	536	905.7	138	244.7	534	769.2	332	386.3
Leptocottus armatus	Pacific staghorn sculpin	9	13.2	14	18.3	10	16.0	22	32.8	12	16.1	6	9.2	18	33.4	55	92.3	36	50.9	29	33.5
Leuroglossus stilbius	California smoothtongue																				
Liparis fucensis	slipskin snailfish																				
Liparis spp.	snailfishes																				
Oligocottus spp.	sculpins																			20	29.5
Ophidiidae unid.	cusk-eels																				
Ophiodon elongatus	lingcod																				
Osmeridae unid.	smelts	1	1.4	1	1.2																
Oxylebius pictus	painted greenling																				
Parophrys vetulus	English sole																				
Pholididae unid.	gunnels																				
Pleuronectes bilineatus	rock sole																				
Pleuronectes isolepis	butter sole																				
Pleuronectidae unid.	flounders			1	1.4																
Pleuronectiformes unid.	flatfishes																				
Psettichthys melanostictus	sand sole																				
Ruscarius creaseri	rouchcheek sculpin																				
Sardinops sagax	Pacific sardine																				
Scorpaenichthys marmoratus	cabezon																				
Sebastes spp.	rockfishes																				
Sebastes spp. V	rockfishes																				
Sebastes spp. V_D	rockfishes																				
Sebastes spp. V_De	rockfishes																				
Sebastes spp. VD	rockfishes																				
Sebastes spp. VP	rockfishes																				
Sebastolobus spp.	thornyheads																				
Stenobrachius leucopsarus	northern lampfish																			1	1.6
Stichaeidae unid.	pricklebacks																				
Syngnathidae unid.	pipefishes			1	1.1																
Syngnathus spp.	pipefishes																	1	1.3		
Tarletonbeania crenularis	blue lanternfish																				
Typhlogobius californiensis	blind goby																			1	1.2
	FISH TOTALS:	1,851		993		1,322		1,069		2,325		620		798		727		1,079		1,169	
Cancer antennarius (megalops)	brown rock crab					3	5.1			3	3.9	3	3.7					1	1.3		
Cancer anthonyi (megalops)	yellow rock crab	1	1.4	2	2.8	2	3.4			2	2.4	1	1.2	1	1.9	1	1.7	2	3.2	1	1.1
Cancer gracilis (megalops)	slender rock crab					1	1.7			1	1.2							1	1.3		
Cancer jordani (megalops)	hairy rock crab					1	1.7			1	1.2	1	1.2	1	1.9			1	1.3		
Cancer magister (megalops)	dungeness crab																				
Cancer productus (megalops)	red rock crab	1	1.4							1	1.4							1	1.3	1	0.8
Cancer spp. (megalops)	unidentified cancer crabs			1	1.3															1	1.3
Carcinus maenas (megalops)	European green crab																			1	1.1
	CRAB TOTALS:	2		3		7		0		8		5		2		1		6		4	

Table 4-1. (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa and Megalops of *Cancer* spp. and European Green Crabs Collected in front of the Moss Landing Power Plant New Combined-cycle Units and Units 6 and 7 Intakes: March 2, 1999 through February 24, 2000.

Taxon	Common Name	Survey 31 December 9 - 10, 1999				Survey 32 December 16 - 17, 1999				Survey 33 December 21 - 22, 1999				Survey 34 December 29 - 30, 1999				Survey 35 January 6 - 7, 2000			
		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12	
		Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.
Ammodytes hexapterus	Pacific sand lance																				
Artedius lateralis	smoothhead sculpin																				
Artedius spp.	sculpins																				
Atherinidae unid.	silversides															1	1.7	3	5.7		
Atherinops affinis	topsmelt																				
Atherinopsis californiensis	jacksmelt	7	11.6	20	27.4	36	50.8	6	10.7	3	4.4	5	6.5					8	15.7	12	22.1
Aulorhynchus flavidus	tubesnout																				
Bathylagus ochotensis	popeye blacksmelt																				
Bathymasteridae unid.	ronquils																				
Blennioidei	blennies																				
Brosmophycis marginata	red brotula																				
Cebidichthys violaceus	monkeyface eel																				
Chaenopsidae unid.	tube blennies																				
Citharichthys sordidus	Pacific sanddab													1	1.6						
Citharichthys stigmaeus	speckled sanddab															1	1.9	1	1.2		
Clinocottus analis	wooly sculpin																				
Clupea pallasii	Pacific herring			3	3.9					3	4.3	8	11.8	6	10.7	3	5.3				
Clupeidae unid.	herrings									1	1.5										
Clupeiformes	herrings and anchovies																				
Coryphopterus nicholsi	blackeye goby	5	8.1					1	1.2	1	1.2	5	6.8	1	1.6						
Cottidae unid.	sculpins													11	18.6	3	5.4				
Cottus asper	prickly sculpin																				
Engraulis mordax	northern anchovy	8	13.5	6	8.5	6	8.2	8	14.2	13	19.6	33	47.6	1	1.7			7	14.6	10	16.7
Genyonemus lineatus	white croaker	5	7.9	2	2.5	112	170.1	26	43.0	146	226.4	47	69.4	6	9.2	1	1.6	5	9.8	4	6.9
Gibbonsia spp.	clinid kelpfishes			1	1.4	1	1.8	1	1.6												
Gillichthys mirabilis	longjaw mudsucker	17	24.8	45	60.8	9	12.7	7	10.9	13	19.1	25	35.0	11	18.6	9	15.2	18	36.5	11	17.1
Gobiesocidae unid.	clingfishes																				
Gobiesox spp.	clingfishes																				
Gobiidae - type I	gobies																				
Gobiidae unid.	gobies	321	532.5	226	331.3	554	767.2	351	527.2	238	347.2	191	274.5	424	714.5	233	395.7	216	426.2	146	254.5
Hexagrammidae unid.	greenlings																				
Hypsoblennius spp.	blennies	1	1.6																		
larval fish - damaged	unidentified larval fishes	1	1.8					4	6.5			3	3.7							3	6.1
larval fish fragment	unidentified larval fishes	1	1.6	2	3.9	11	16.2	12	18.2	1	1.7	4	5.7	5	9.3	4	6.6	1	1.8	6	11.0
larval/post-larval fish, unid.	unidentified larval fishes																				
Lepidogobius lepidus	bay goby	482	772.7	362	611.1	223	334.0	176	250.7	201	283.5	200	257.2	278	460.6	69	119.6	317	589.6	134	230.1
Leptocottus armatus	Pacific staghorn sculpin	13	19.8	22	32.8	163	224.7	108	181.7	36	56.9	69	98.8	17	27.4	9	14.6	21	39.2	20	34.4
Leuroglossus stilbius	California smoothtongue																				
Liparis fucensis	slipskin snailfish																				
Liparis spp.	snailfishes																				
Oligocottus spp.	sculpins							1	1.6					1	1.6						
Ophidiidae unid.	cusk-eels																				
Ophiodon elongatus	lingcod																				
Osmeridae unid.	smelts															1	1.7				
Oxylebius pictus	painted greenling			1	1.5																
Parophrys vetulus	English sole																				
Pholididae unid.	gunnels																				
Pleuronectes bilineatus	rock sole																				
Pleuronectes isolepis	butter sole																				
Pleuronectidae unid.	flounders											1	1.2								
Pleuronectiformes unid.	flatfishes															1	1.9				
Psettichthys melanostictus	sand sole																				
Ruscarius creaseri	rouchcheek sculpin																				
Sardinops sagax	Pacific sardine																				
Scorpaenichthys marmoratus	cabezon	4	5.7															1	1.8		
Sebastes spp.	rockfishes																				
Sebastes spp. V	rockfishes													2	3.1	1	1.3	1	1.8		
Sebastes spp. V_D	rockfishes																				
Sebastes spp. V_De	rockfishes																				
Sebastes spp. VD	rockfishes																				
Sebastes spp. VP	rockfishes																				
Sebastolobus spp.	thornyheads																				
Stenobrachius leucopsarus	northern lampfish	5	7.5	2	3.3	15	24.4	3	5.2	8	12.7	3	4.8	28	48.5	25	43.2				
Stichaeidae unid.	pricklebacks																				
Syngnathidae unid.	pipefishes																				
Syngnathus spp.	pipefishes			2	3.0																
Tarletonbeania crenularis	blue lanternfish					3	5.2	3	4.4	1	1.2	3	5.5			3	5.2				
Typhlogobius californiensis	blind goby																				
	FISH TOTALS:	870		694		1,133		707		665		597		792		364		599		346	
Cancer antennarius (megalops)	brown rock crab			1	1.5	1	1.6			2	3.2	1	1.2					5	9.5	1	1.7
Cancer anthonyi (megalops)	yellow rock crab	6	8.4	6	8.0	13	16.3	5	8.4	7	11.0	2	2.9								
Cancer gracilis (megalops)	slender rock crab	1	1.5							1	1.6			1	2.0						
Cancer jordani (megalops)	hairy rock crab													1	2.0						
Cancer magister (megalops)	dungeness crab																				
Cancer productus (megalops)	red rock crab	1	1.3	1	1.2													1	2.0		
Cancer spp. (megalops)	unidentified cancer crabs																				
Carcinus maenas (megalops)	European green crab																				
	CRAB TOTALS:	8		8		14		5		10		3		2		0		6		1	

Table 4-1. (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa and Megalops of *Cancer* spp. and European Green Crabs Collected in front of the Moss Landing Power Plant New Combined-cycle Units and Units 6 and 7 Intakes: March 2, 1999 through February 24, 2000.

Taxon	Common Name	Survey 36				Survey 37				Survey 38				Survey 39			
		January 13 - 14, 2000				January 20 - 21, 2000				January 27 - 28, 2000				February 3 - 4, 2000			
		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12	
		Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.
Ammodytes hexapterus	Pacific sand lance					3	5.7	1	1.9	3	4.8	2	3.1	59	99.6	42	77.8
Artedius lateralis	smoothhead sculpin																
Artedius spp.	sculpins	1	2.1														
Atherinidae unid.	silversides															1	1.9
Atherinops affinis	topsmelt																
Atherinopsis californiensis	jacksmelt					4	7.9	4	6.8	18	31.6	22	32.2	6	9.8	10	18.1
Aulorhynchus flavidus	tubesnout															1	1.4
Bathylagus ochotensis	popeye blacksmelt							1	1.7								
Bathymasteridae unid.	ronquils																
Blennioidei	blennies																
Brosmophycis marginata	red brotula																
Cebidichthys violaceus	monkeyface eel									14	25.9	3	4.7				
Chaenopsidae unid.	tube blennies																
Citharichthys sordidus	Pacific sanddab																
Citharichthys stigmaeus	speckled sanddab									1	2.2			2	3.5		
Clinocottus analis	wooly sculpin																
Clupea pallasii	Pacific herring			1	1.8	1	2.0	3	5.2	6	12.0	35	61.0	66	109.5	157	285.0
Clupeidae unid.	herrings													1	1.4		
Clupeiformes	herrings and anchovies							1	2.1	2	3.8			3	5.0		
Coryphopterus nicholsi	blackeye goby	22	34.7									3	4.7	2	3.4		
Cottidae unid.	sculpins			2	3.2	2	3.2	1	2.0			1	1.9	2	3.4	2	3.4
Cottus asper	prickly sculpin							2	3.5	11	20.8	8	13.0	3	4.6	15	29.5
Engraulis mordax	northern anchovy							11	22.1	5	9.4	4	6.4	3	5.1	4	7.0
Genyonemus lineatus	white croaker	1	1.7	1	1.7					21	33.7	13	20.2	22	37.4	5	8.9
Gibbonsia spp.	clinid kelpfishes																
Gillichthys mirabilis	longjaw mudsucker	3	5.2	6	9.5	3	6.0	5	9.1	2	4.0	2	3.2	5	8.8	2	3.5
Gobiesocidae unid.	clingfishes																
Gobiesox spp.	clingfishes																
Gobiidae - type I	gobies																
Gobiidae unid.	gobies	284	492.2	200	319.0	146	249.2	108	195.6	414	792.8	254	446.4	351	601.2	220	393.8
Hexagrammidae unid.	greenlings																
Hypsoblennius spp.	blennies																
larval fish - damaged	unidentified larval fishes											1	2.2			3	5.5
larval fish fragment	unidentified larval fishes			2	3.0	1	1.7			6	11.1	2	3.5	2	3.8	4	7.2
larval/post-larval fish, unid.	unidentified larval fishes																
Lepidogobius lepidus	bay goby	282	509.5	62	98.7	221	367.9	121	209.4	305	577.1	198	355.5	459	797.0	177	312.8
Leptocottus armatus	Pacific staghorn sculpin	29	48.6	20	34.0	56	104.3	65	118.9	28	52.7	33	56.9	37	63.1	60	106.3
Leuroglossus stilbius	California smoothtongue																
Liparis fucensis	slipskin snailfish																
Liparis spp.	snailfishes													1	1.7		
Oligocottus spp.	sculpins																
Ophidiidae unid.	cusk-eels													1	1.7		
Ophiodon elongatus	lingcod																
Osmeridae unid.	smelts	53	88.8	10	17.0	2	3.3	3	5.6	9	16.7	5	7.3	23	38.3	28	50.7
Oxylebius pictus	painted greenling																
Parophrys vetulus	English sole																
Pholididae unid.	gunnels															1	1.7
Pleuronectes bilineatus	rock sole																
Pleuronectes isolepis	butter sole																
Pleuronectidae unid.	flounders													3	5.6	2	3.4
Pleuronectiformes unid.	flatfishes					1	2.0	3	5.3	3	4.9	1	1.6	5	8.5		
Psettichthys melanostictus	sand sole													2	3.5		
Ruscarius creaseri	rouchcheek sculpin																
Sardinops sagax	Pacific sardine					2	4.0	1	2.1								
Scorpaenichthys marmoratus	cabezon																
Sebastes spp.	rockfishes							1	1.5								
Sebastes spp. V	rockfishes					2	3.4	2	3.2								
Sebastes spp. V_D	rockfishes																
Sebastes spp. V_De	rockfishes																
Sebastes spp. VD	rockfishes					1	2.0										
Sebastes spp. VP	rockfishes																
Sebastolobus spp.	thornyheads									2	3.1						
Stenobrachius leucopsarus	northern lampfish	1	2.1											3	5.0	3	5.2
Stichaeidae unid.	pricklebacks																
Syngnathidae unid.	pipefishes																
Syngnathus spp.	pipefishes																
Tarletonbeania crenularis	blue lanternfish																
Typhlogobius californiensis	blind goby																
	FISH TOTALS:	676		304		445		333		850		587		1,061		737	
Cancer antennarius (megalops)	brown rock crab					2	3.9			1	1.8						
Cancer anthonyi (megalops)	yellow rock crab	1	2.1			1	2.0					1	1.8				
Cancer gracilis (megalops)	slender rock crab					2	4.0							2	3.2	3	6.0
Cancer jordani (megalops)	hairy rock crab	1	1.7	2	3.3			1	2.1			1	1.7				
Cancer magister (megalops)	dungeness crab																
Cancer productus (megalops)	red rock crab	1	1.7											1	1.7	3	5.6
Cancer spp. (megalops)	unidentified cancer crabs																
Carcinus maenas (megalops)	European green crab																
	CRAB TOTALS:	3		2		5		1		1		2		3		6	

Table 4-1. (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa and Megalops of *Cancer* spp. and European Green Crabs Collected in front of the Moss Landing Power Plant New Combined-cycle Units and Units 6 and 7 Intakes: March 2, 1999 through February 24, 2000.

Taxon	Common Name	Survey 40 February 10 - 11, 2000				Survey 41 February 17 - 18, 2000				Survey 42 February 24 - 25, 2000			
		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12		New CC Units N = 12		Units 6&7 N = 12	
		Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.	Ct.	Den.
Ammodytes hexapterus	Pacific sand lance	37	57.2	28	45.5			2	3.0	5	7.7	2	3.0
Artedius lateralis	smoothhead sculpin												
Artedius spp.	sculpins	1	1.6										
Atherinidae unid.	silversides												
Atherinops affinis	topsmelt												
Atherinopsis californiensis	jacksmelt	4	6.3	3	4.6	26	42.9			1	1.7		
Aulorhynchus flavidus	tubesnout												
Bathylagus ochotensis	popeye blacksmelt												
Bathymasteridae unid.	ronquils												
Blennioidei	blennies												
Brosmophycis marginata	red brotula												
Cebidichthys violaceus	monkeyface eel	1	1.6	1	1.6	1	1.5	1	1.8				
Chaenopsidae unid.	tube blennies											1	1.4
Citharichthys sordidus	Pacific sanddab							1	1.7	3	4.1	3	4.6
Citharichthys stigmaeus	speckled sanddab	2	3.2	1	1.7	1	2.0			2	3.0	1	1.4
Clinocottus analis	wooly sculpin			1	1.7							1	1.2
Clupea pallasii	Pacific herring	10	14.8	10	16.1	11	18.5	24	39.1	10	16.9	5	7.4
Clupeidae unid.	herrings									1	1.6		
Clupeiformes	herrings and anchovies	1	1.6							1	1.3		
Coryphopterus nicholsi	blackeye goby	4	5.9	1	1.4			3	5.0	10	14.9	10	14.4
Cottidae unid.	sculpins	5	8.3	6	9.3	4	6.3	20	32.2	2	2.5	19	28.1
Cottus asper	prickly sculpin	1	1.4	1	1.9	18	30.9	17	28.5	18	27.8	5	7.4
Engraulis mordax	northern anchovy	2	3.0			5	7.7	4	6.6	3	4.6	3	4.6
Genyonemus lineatus	white croaker	79	132.0	104	159.6	54	87.0	45	73.1	45	69.4	52	74.7
Gibbonsia spp.	clinid kelpfishes			2	3.0								
Gillichthys mirabilis	longjaw mudsucker	3	4.7	2	3.0	4	7.0	13	21.7	11	16.5	14	20.3
Gobiesocidae unid.	clingfishes												
Gobiesox spp.	clingfishes												
Gobiidae - type I	gobies												
Gobiidae unid.	gobies	728	1102.4	313	491.1	850	1338.4	314	537.7	727	1088.4	493	707.9
Hexagrammidae unid.	greenlings												
Hypsoblennius spp.	blennies									1	1.6		
larval fish - damaged	unidentified larval fishes	1	1.4	3	5.0	8	14.3			15	21.8	4	5.9
larval fish fragment	unidentified larval fishes	7	9.6	17	27.7	13	21.6	10	17.1	29	44.9	11	16.2
larval/post-larval fish, unid.	unidentified larval fishes	2	2.7					3	4.9	1	1.5		
Lepidogobius lepidus	bay goby	240	360.8	67	109.9	160	248.3	121	205.1	107	154.0	161	227.8
Leptocottus armatus	Pacific staghorn sculpin	25	38.0	14	21.7	35	59.5	47	78.9	26	41.0	27	39.9
Leuroglossus stilbius	California smoothtongue												
Liparis fucensis	slipskin snailfish												
Liparis spp.	snailfishes	1	1.4							1	1.6		
Oligocottus spp.	sculpins			1	1.5								
Ophidiidae unid.	cusk-eels												
Ophiodon elongatus	lingcod					1	1.5						
Osmeridae unid.	smelts					14	23.3	7	11.9	12	19.3	17	25.0
Oxylebius pictus	painted greenling												
Parophrys vetulus	English sole	1	1.7			1	2.1			1	1.3	1	1.2
Pholididae unid.	gunnels									1	1.6		
Pleuronectes bilineatus	rock sole	3	4.6							1	1.5	7	9.7
Pleuronectes isolepis	butter sole									2	3.0		
Pleuronectidae unid.	flounders	6	9.6	2	3.2	2	3.0	4	6.7	24	35.5	9	12.2
Pleuronectiformes unid.	flatfishes			2	2.8	2	3.1			4	5.5	3	4.6
Psettichthys melanostictus	sand sole	1	2.1										
Ruscarius creaseri	rouchcheek sculpin												
Sardinops sagax	Pacific sardine												
Scorpaenichthys marmoratus	cabezon												
Sebastes spp.	rockfishes	1	1.4										
Sebastes spp. V	rockfishes							1	1.6	4	5.7	4	5.5
Sebastes spp. V_D	rockfishes												
Sebastes spp. V_De	rockfishes					1	1.5					1	1.6
Sebastes spp. VD	rockfishes											1	1.2
Sebastes spp. VP	rockfishes												
Sebastolobus spp.	thornyheads					8	12.6	9	14.8	34	52.6	21	30.0
Stenobrachius leucopsarus	northern lampfish			1	1.5	1	1.5	1	1.6	142	221.5	74	107.4
Stichaeidae unid.	pricklebacks	1	1.4							1	1.8	1	1.4
Syngnathidae unid.	pipefishes												
Syngnathus spp.	pipefishes												
Tarletonbeania crenularis	blue lanternfish			1	1.4					8	12.8	3	4.5
Typhlogobius californiensis	blind goby												
	FISH TOTALS:	1,167		581		1,220		647		1,253		954	
Cancer antennarius (megalops)	brown rock crab												
Cancer anthonyi (megalops)	yellow rock crab												
Cancer gracilis (megalops)	slender rock crab	2	3.2	1	1.4			2	3.5			1	1.4
Cancer jordani (megalops)	hairy rock crab	1	1.4			1	1.5	1	1.7				
Cancer magister (megalops)	dungeness crab												
Cancer productus (megalops)	red rock crab			1	1.4							2	3.2
Cancer spp. (megalops)	unidentified cancer crabs												
Carcinus maenas (megalops)	European green crab												
	CRAB TOTALS:	3		2		1		3		0		3	

4.1.1 Sampling and Laboratory Processing Sufficiency

The accumulation of species during entrainment sampling through July at MLPP followed expected patterns with rapid accumulation during early sampling efforts that decreased with continued sampling (Figures 4-2 and 4-3). Differences in the total number of taxa collected and the rate of taxa accumulation were noted between sampling stations. A total of 64 taxa was collected at the new combined-cycle units intake while 57 taxa were collected from the Units 6 and 7 intake over the entire year of surveys. The taxa collected at the new combined-cycle units intake that were not collected at the Units 6 and 7 intake from March 2 through February 24, 2000 are shown in Table 4-2. The taxa that were unique to the Units 6 and 7 intake are also shown in Table 4-2.

Table 4-2. Species found to be Unique to either the New Combined-cycle Units or the Units 6 and 7 Intakes. Data from Surveys 1 through 42.

Taxa unique to the New combined-cycle Units intake		*Taxa unique to the Units 6 and 7 intake*	
Taxon	Common Name	Taxon	Common Name
Scorpaenichthys marmoratus	cabezon	*Aulorhynchus flavidus*	tubesnout
Ophiodon elongatus	lingcod	*Pleuronectes bilineatus*	rock sole
Leuroglossus stilbius	California smoothtongue	*Liparis fucensis*	slipskin snailfish
Bathymasteridae unid.	ronquil	*Typhlogobius californiensis*	blind goby
Ophidiidae unid.	cuskeel	*Bathylagus ochotensis*	popeye blacksmelt
Sebastes spp. VP	rockfish		
Sebastes spp. V_D	rockfish		
Pleuronectes isolepis	butter sole		
Gobiidae - type I	unidentified goby		
Gobiesocidae unid.	unidentified clingfish		
Liparis spp.	unidentified snailfish		
Brosmophycis marginata	red brotula		
Hexagrammidae unid.	greenling		

Mean concentrations (#/m^3) for fishes collected from the stations in front of the new combined-cycle units and the Units 6 and 7 intakes during Surveys 1 through 42 were based on two replicate samples collected at each location during a cycle. These data included all six cycles for Surveys 1 through 42. A total of 251 paired samples was analyzed to determine if differences in species abundances between the two sampling areas could be detected. If no differences were detected, laboratory processing could be reduced to a single representative location. Although 70 larval fish taxa groups were collected from these samples, only 51 taxa were collected at both locations.

The mean concentrations of the 51 taxa collected at both locations were analyzed statistically using a paired t-test (Table 4-3). The concentrations for both locations were transformed using

$\log_{10}(x+.01)$ to look at relative differences between the two intakes and to account for some of the differences in abundance between sampling events. Of the 51 taxa collected in both areas, significant differences (α=0.05) between the two intakes were detected in seven taxa: blackeye goby *Coryphopterus nicholsi*, Pacific herring *Clupea pallasi*, white croaker *Genyonemus lineatus*, longjaw mudsucker *Gillichthys mirabilis*, prickly sculpin *Cottus asper*, bay goby *Lepidogobius lepidus*, and English sole *Parophrys vetulus*. Pacific herring, longjaw mudsucker and prickly sculpin were collected in significantly higher concentrations at the Units 6 and 7 intake while the other four taxa were collected in significantly higher concentrations at the new combined-cycle units intake.

Table 4-3. Results of T-tests Comparing Larval Fish Concentrations at the New Combined-cycle Units and the Units 6 and 7 Intakes Collected during Surveys 1 through 42.

Taxon	Log (x+.01) Differences Between New CC Units and Units 6 and 7					
	Mean Difference	No.	Std. Error	T-Value	Probability of T	Power of Test
Pholididae unid.	-0.001211	251	0.032334	-0.593	0.5535	0.0003
Gibbonsia spp.	-0.004322	251	0.055453	-1.235	0.2181	0.0103
Atherinidae unid.	0.007636	251	0.140047	0.864	0.3885	0.0010
Oxylebius pictus	0.006115	251	0.055813	1.736	0.0838	0.1979
Coryphopterus nicholsi	0.048571	251	0.347901	2.212	0.0279	0.8419
Cebidichthys violaceus	0.017540	251	0.170433	1.630	0.1043	0.1153
Engraulis mordax	-0.017797	251	0.172066	-1.639	0.1025	0.1205
Artedius lateralis	-0.000232	251	0.034172	-0.108	0.9144	0.0001
Pleuronectidae unid.	0.000344	251	0.104702	0.052	0.9585	0.0001
Artedius spp.	-0.010929	251	0.108357	-1.598	0.1113	0.0964
Stichaeidae unid.	0.003327	251	0.043853	1.202	0.2306	0.0083
Syngnathus spp.	0.001362	251	0.040135	0.537	0.5914	0.0002
Sebastes spp.	-0.000084	251	0.024152	-0.055	0.9560	0.0001
larval/post-larval fish, unid.	0.005447	251	0.086996	0.992	0.3222	0.0022
Citharichthys stigmaeus	0.007350	251	0.071270	1.634	0.1035	0.1175
Citharichthys sordidus	0.000399	251	0.054968	0.115	0.9084	0.0001
Clinocottus analis	0.003660	251	0.053736	1.079	0.2816	0.0038
Chaenopsidae unid.	-0.003356	251	0.076405	-0.696	0.4871	0.0004
Sebastes spp. V	0.003238	251	0.054746	0.937	0.3497	0.0016
Sebastes spp. V_De	0.007043	251	0.108888	1.025	0.3065	0.0027
Ruscarius creaseri	-0.001586	251	0.042344	-0.593	0.5536	0.0003
larval fish - damaged	-0.004484	251	0.146928	-0.483	0.6292	0.0002
Hypsoblennius spp.	0.013933	251	0.236369	0.934	0.3513	0.0015
Sebastes spp. VD	0.001323	251	0.030167	0.695	0.4879	0.0004
Sebastolobus spp.	0.003738	251	0.067157	0.882	0.3788	0.0011
Clupeiformes	0.001750	251	0.077657	0.357	0.7214	0.0001
Clupea pallasii	-0.100821	251	0.305518	-5.228	0.0000	1.0000

Table 4-3 (continued). Results of T-tests Comparing Larval Fish Concentrations at the New Combined-cycle Units and the Units 6 and 7 Intakes Collected during Surveys 1 through 42.

Taxon	**Log (x+.01) Differences Between New CC Units and Units 6 and 7**					
	Mean Difference	**No.**	**Std. Error**	**T-Value**	**Probability of T**	**Power of Test**
Gillichthys mirabilis	-0.046184	251	0.292771	-2.499	0.0131	0.9903
Ammodytes hexapterus	0.006091	251	0.115851	0.833	0.4057	0.0009
Cottus asper	-0.033287	251	0.205230	-2.570	0.0108	0.9964
Lepidopsetta bilineata	0.001814	251	0.047546	0.604	0.5461	0.0003
Cottidae unid.	-0.022078	251	0.195222	-1.792	0.0744	0.2562
Syngnathidae unid.	0.000053	251	0.031681	0.027	0.9787	0.0001
Atherinopsis californiensis	0.024535	251	0.216161	1.798	0.0734	0.2637
Genyonemus lineatus	0.058214	251	0.224344	4.111	0.0001	1.0000
Oligocottus spp.	-0.007439	251	0.088453	-1.332	0.1839	0.0193
Lepidogobius lepidus	0.118776	251	0.499288	3.769	0.0002	1.0000
Gobiidae unid.	0.000754	251	0.440226	0.027	0.9784	0.0001
Leptocottus armatus	0.003605	251	0.280957	0.203	0.8391	0.0001
Parophrys vetulus	0.008119	251	0.052630	2.444	0.0152	0.9806
Psettichthys melanostictus	0.002889	251	0.038792	1.180	0.2392	0.0072
Osmeridae unid.	0.000797	251	0.222088	0.057	0.9547	0.0001
Tarletonbeania crenularis	-0.003595	251	0.068796	-0.828	0.4085	0.0008
Stenobrachius leucopsarus	0.015333	251	0.148237	1.639	0.1025	0.1206
Clupeidae unid.	-0.003167	251	0.071103	-0.706	0.4810	0.0004
Gobiesox spp.	0.000156	251	0.024578	0.101	0.9198	0.0001
Pleuronectiformes unid.	0.005266	251	0.079146	1.054	0.2929	0.0032
Sardinops sagax	0.000715	251	0.011331	1.000	0.3183	0.0023
larval fish fragment	0.010356	251	0.245525	0.668	0.5046	0.0004
Blennioidei	-0.000791	251	0.031731	-0.395	0.6931	0.0001
Atherinops affinis	-0.005257	251	0.078069	-1.067	0.2871	0.0035

Preliminary results — quality control checks incomplete

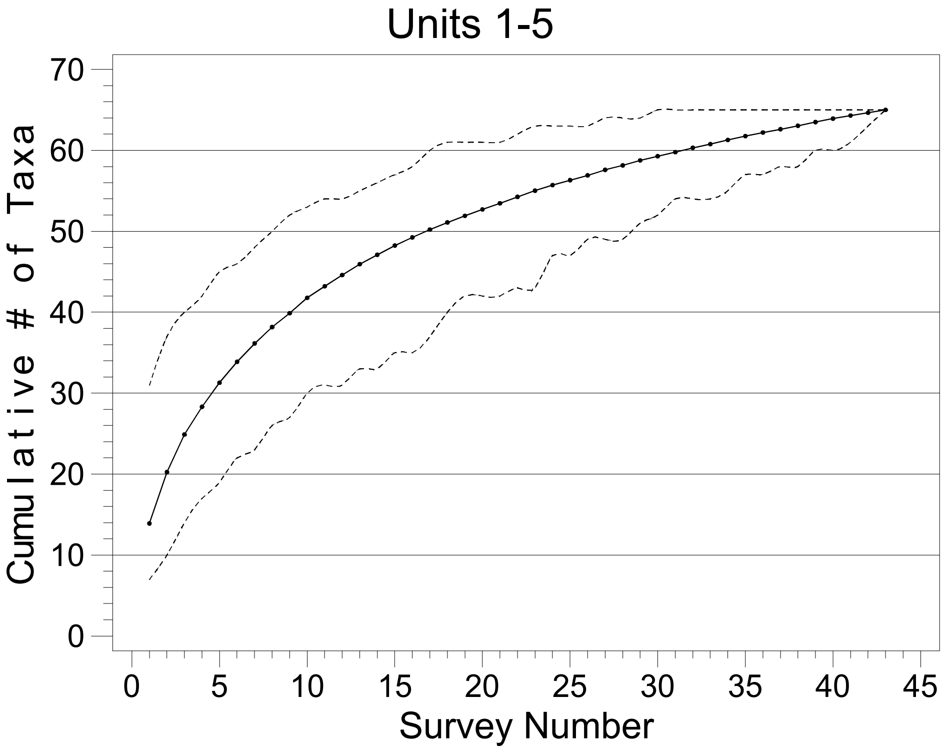


Figure 4-2. Mean (dotted line), maximum and minimum (dashed upper and lower lines) cumulative numbers of species from 1,000 iterations of data collected over 42 surveys at the new combined-cycle units intake.

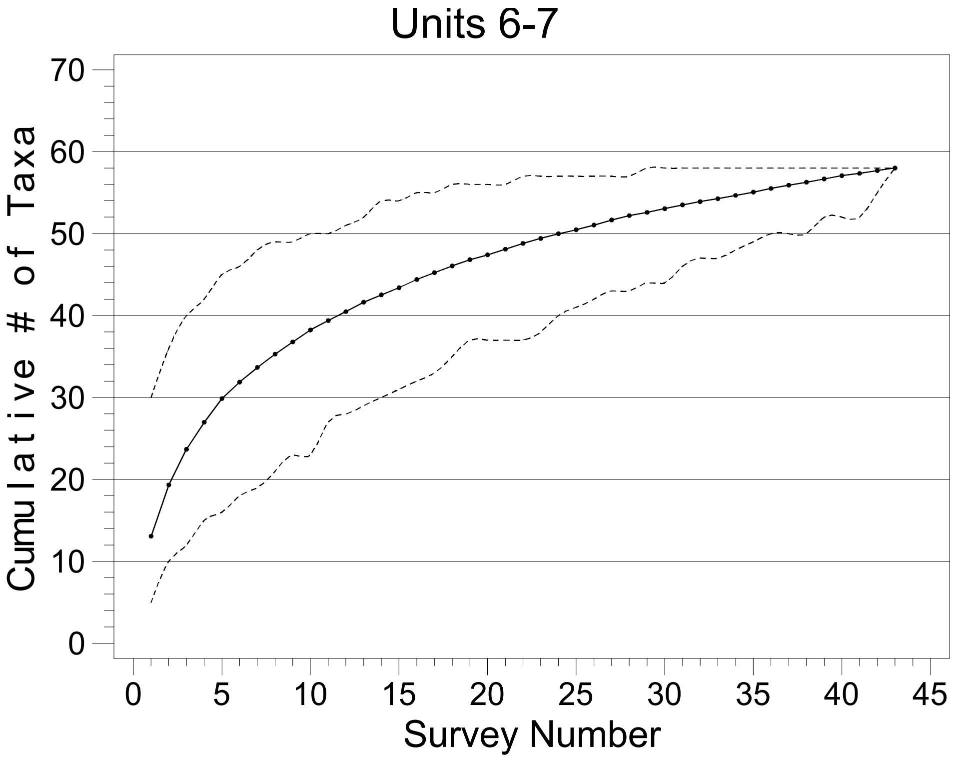


Figure 4-3. Mean (dotted line), maximum and minimum (dashed upper and lower lines) cumulative numbers of species from 1,000 iterations of data collected over 42 surveys at the Units 6 and 7 intake.

The power of the data to detect a difference between intakes if one actually existed was calculated for the taxa groups with data from both intakes. In the taxa where no differences were detected, the low estimates of power (all < 0.80) indicated that it would be difficult to conclude from the data for those taxa that no significant difference between intakes existed. Although statistical power usually increases with sample size it is also affected by variance. The variance increased with sample size reducing the power of the tests. The number of significant differences between units for the 51 taxa is greater than one would expect based on a 95 percent probability level. These data indicate that there are both qualitative and quantitative differences between the two intakes.

4.1.2 Day-Night Comparison

ETM and proportional entrainment (*PE*) values are based on daytime estimates of entrainment and source water larval concentrations. Because the unmarked Elkhorn Sough channel cannot be safely navigated other than during daytime hours, calculation of *ETM* values (and P_M) must rely on daytime source and entrainment sampling results. Intake effects are also estimated when possible using fecundity hindcasting (*FH*) and adult equivalent loss (*AEL*) models based on daytime and nighttime entrainment samples. Twelve months of weekly entrainment samples (March 1999 to March 2000) have been collected for these analyses in the routine 24-hour entrainment sampling described in Section 3.

Generally higher concentrations of larvae were collected in nighttime entrainment samples. These diurnal changes in larval concentrations found in our 24-hour samples results are important measurements in accurately estimating of total entrainment. The total entrainment values are used in both the fecundity hindcast (*FH*) and adult equivalent loss (*AEL*) models to estimate entrainment losses. These daytime and nighttime changes in the concentration of entrained larvae are unimportant using an *ETM* model of entrainment loss, if the ratio of entrainment to source water concentrations remain the same throughout the day.

Since source water stations in the Elkhorn Slough could only be safely sampled during daylight hours, members of the TWG requested that we test for diurnal changes in proportional entrainment using two source water stations that could be safely sampled at night. A separate source water survey was conducted on January 27 and 28, 2000 and another conducted on February 3 and 4, 2000 at the Harbor Bridge (HB) and Harbor Mouth (HM) stations shown in Figure 3-1. Samples were collected to coincide with each of the six cycles in the 24-hour entrainment surveys. The time of day for each collection cycle 1 through 6 are listed in Table 4-4. Prior to completing these surveys and analyses, we first conducted a test using 24-hour data from neighboring entrainment stations (new combined-cycle units and Units 6 and 7 intakes).

Results of 24-hour entrainment sampling (6 sampling cycles, four hours apart) clearly indicate significant increases in evening and nighttime larval abundance, peaking in the middle of the night. Hypothetically, increases in entrainment larval concentrations should be accompanied by similar, if not identical increases in source water concentrations. Since information on nighttime source-water concentrations is not available, we cannot make a direct test of this hypothesis. Instead, we compared the ratio of 24-hour larval concentrations collected at the neighboring Units 6 and 7 entrainment sampling station.

Concentrations of unidentified Gobiidae, the most consistently abundant larval taxa, were used to provide the largest number of paired station samples. Results from 29 weekly 24-hr entrainment surveys (1-28 and 34) collected from the stations of the new combined-cycle and Units 6 and 7 intakes were used in the comparison. Results from Survey 13, cycle 4; Survey 14, cycle 5 and Survey 16, cycle 5 were not used in the analysis due to the extreme, outlying nature of the three values. The values may represent either a rare set of yet unexplained circumstances or experimental error. We will continue to investigate these separated results. Concentrations from the two areas were compared by simple ratio of replicate samples as closely paired in time as possible.

The test results indicate the ratio of unidentified Gobiidae larval concentrations between the two stations change roughly 75 percent between day and night. The decreased nighttime similarity of the two stations may reflect the presence of a hydraulic transition zone between the two stations, where more outgoing tidal flows from Elkhorn Slough bearing concentrations of larvae reach the combined-cycle area than the area of the Units 6 and 7 intake. The existence of such a hydraulic pattern would be amplified by the late nighttime hours (cycles 4 and 5) by higher concentrations of larvae from the slough. Although we continue below to compare these findings to results from nighttime samples collected at the Harbor Bridge and Harbor Mouth stations, the spatial effects seen in the first test results seem to preclude the possibility of converting daytime source water concentrations to nighttime concentrations.

Table 4-4. Sample Collection Times (PST) by Cycle, Date and Source Water Stations, Harbor Mouth (HM) and Harbor Bridge (HB).

Cycle	Harbor Mouth		Harbor Bridge	
	01/27/2000	02/03/2000	01/27/2000	02/03/2000
1	10:55	11:12	10:45	10:58
2	14:39	14:43	14:28	14:29
3	18:42	18:49	18:32	18:37
4	22:38	22:48	22:27	22:34
5	2:51	2:47	2:34	2:33
6	6:43	6:45	6:30	6:33

The results of a daytime and nighttime survey of two source water stations revealed no clear pattern of either higher or lower entrainment proportions with respect to time of day. The concentrations of the three larval taxa, unidentified gobies, bay goby, and Pacific staghorn sculpin, that were consistently present in both entrainment and source water samples are compared in Tables 4-5 and 4-6. Ratios shown in the table were calculated by dividing the species' larval concentrations collected at the new CC units intake entrainment station by their concentrations at the Harbor Mouth (HM) and Harbor Bridge (HB) stations. The results are tabulated for the three taxa by survey date and the six sampling cycles. The average of all of the species' ratios by time of day (sampling cycle) ranges from 1.5 to 12.8 with minimum values of 0.1 to maximum values of 57. The results were highly variable with no clear pattern of nighttime and daytime differences in proportion of entrainment and source water larval concentrations from the harbor stations. The effect of tidal currents on distribution of larval fishes from the Elkhorn Slough and Monterey Bay would be expected to represent a large source of variation among source water stations and the ratio of entrainment and source water concentrations.

Table 4-5. Ratio of Daytime and Nighttime Concentrations of Larval Unidentified Goby Taxa, Bay Goby, and Pacific Staghorn Sculpin Collected at the Harbor Mouth (HM) Station to New CC Units Intake Station Entrainment Concentrations.

HM Cycle	Unidentified Gobies		Bay Goby		Pacific Staghorn Sculpin				
	01/27/2000	02/03/2000	01/27/2000	02/03/2000	01/27/2000	02/03/2000	MEAN	MIN	MAX
1	2.14	0.23	4.47	0.71	*	*	1.89	0.23	4.47
2	2.25	0.34	19.99	1.03	0.41	0.25	4.05	0.25	19.99
3	0.30	10.95	1.07	54.25	2.40	0.56	11.59	0.30	54.25
4	1.07	*	1.28	57.10	2.71	1.60	12.75	1.07	57.10
5	7.90	0.84	4.93	2.47	0.47	1.30	2.99	0.47	7.90
6	0.45	14.57	0.39	21.07	3.42	0.98	6.81	0.39	21.07

*No value can be computed.

Table 4-6. Ratio of Daytime and Nighttime Concentrations of Larval Unidentified Goby Taxa, Bay Goby, and Pacific Staghorn Sculpin Collected at the Harbor Bridge (HB) Station to New CC Units Intake Station Entrainment Concentrations.

HB Cycle	Unidentified Gobies		Bay Goby		Pacific Staghorn Sculpin				
	01/27/2000	02/03/2000	01/27/2000	02/03/2000	01/27/2000	02/03/2000	MEAN	MIN	MAX
1	2.20	0.19	2.40	0.47	5.62	*	2.18	0.19	5.62
2	3.60	0.35	8.98	1.29	1.05	0.13	2.57	0.13	8.98
3	0.24	2.95	0.78	14.88	1.78	0.99	3.60	0.24	14.88
4	1.04	2.11	1.21	6.72	1.33	2.01	2.40	1.04	6.72
5	1.27	0.70	2.36	2.08	0.74	2.03	1.53	0.70	2.36
6	0.37	10.05	0.34	23.36	3.49	1.15	6.46	0.34	23.36

*No value can be computed.

4.2 Source Water Study Results

Nine monthly surveys have been conducted since the source water study began in June 1999. Initially three stations (Kirby Park, Dairies, and Harbor Bridge) were sampled. Three new stations (Figure 3-1) were added to the source water study in September 1999. Two of these stations are located in Monterey Bay (Ocean North and Ocean South) and one station is located at the mouth of the Moss Landing Harbor (Harbor Mouth). Descriptions of station locations are provided in Table 3-2. Data from these new stations from September 1999 through February 2000 are presented in this report.

The source water was divided into three areas for the purpose of data assessment. To compute larval fish percent composition and to calculate proportional entrainment for "Elkhorn Slough" data were analyzed from the Kirby Park, Dairies, and Harbor Bridge stations for all nine surveys. "Moss Landing Harbor" data were calculated from samples collected at the Harbor Bridge and the new combined-cycle units and the Units 6 and 7 intakes on days when the source water surveys were conducted. The "Ocean" data were calculated from samples collected from the Harbor Bridge Station for the first three surveys (before the new stations were added) and from the new Harbor Mouth and the two new Ocean stations for Surveys 4 through 9.

Eight taxa of larval fishes comprised nearly 95 percent of the total numbers of taxa collected in the Elkhorn Slough area (Figure 4-4). The taxa, listed in decreasing order of abundance were: unidentified gobies (60.4 percent), Pacific herring (10.9 percent), blennies *Hypsoblennius* spp. (6.8 percent), longjaw mudsucker *Gillichthys mirabilis* (5.1 percent), bay goby *Lepidogobius lepidus* (5.0 percent), Pacific staghorn sculpin *Leptocottus armatus* (4.1 percent), blackeye goby *Coryphopterus nicholsi* (1.6 percent), and northern lampfish *Stenobrachius leucopsarus* (1.1 percent).

Ninety-five percent of the total numbers of taxa collected in the Moss Landing Harbor area (Figure 4-4) was represented by many of the same taxa listed above. The taxa, listed in decreasing order of abundance were: unidentified gobies (48.4 percent), bay goby (30.5 percent), *Hypsoblennius* spp. (5.1 percent), blackeye goby (2.9 percent), northern lampfish (2.7 percent), Pacific staghorn sculpin (2.5 percent), longjaw mudsucker (1.6 percent), and white croaker *G. lineatus* (0.9 percent).

Species composition was more varied at the Ocean area. Twelve taxa (including unidentified larval fishes) comprised 96 percent of all taxa (Figure 4-4). The taxa, listed in decreasing order of abundance were: unidentified gobies (36.2 percent), northern lampfish *S. leucopsarus* (27.4 percent), unidentified rockfishes *Sebastes* spp. (6.9 percent), white croaker (4.4 percent), bay goby (4.1 percent), *Hypsoblennius* spp. (3.0 percent), thornyheads *Sebastolobus* spp. (3.0

percent), Pacific staghorn sculpin (2.5 percent), unidentified larval fishes (2.4 percent), blue lanternfish *Tarletonbeania crenularis* (1.7 percent), unidentified flounders Pleuronectidae (1.5 percent), and Pacific sand lance *Ammodytes hexapterus* (1.2 percent).

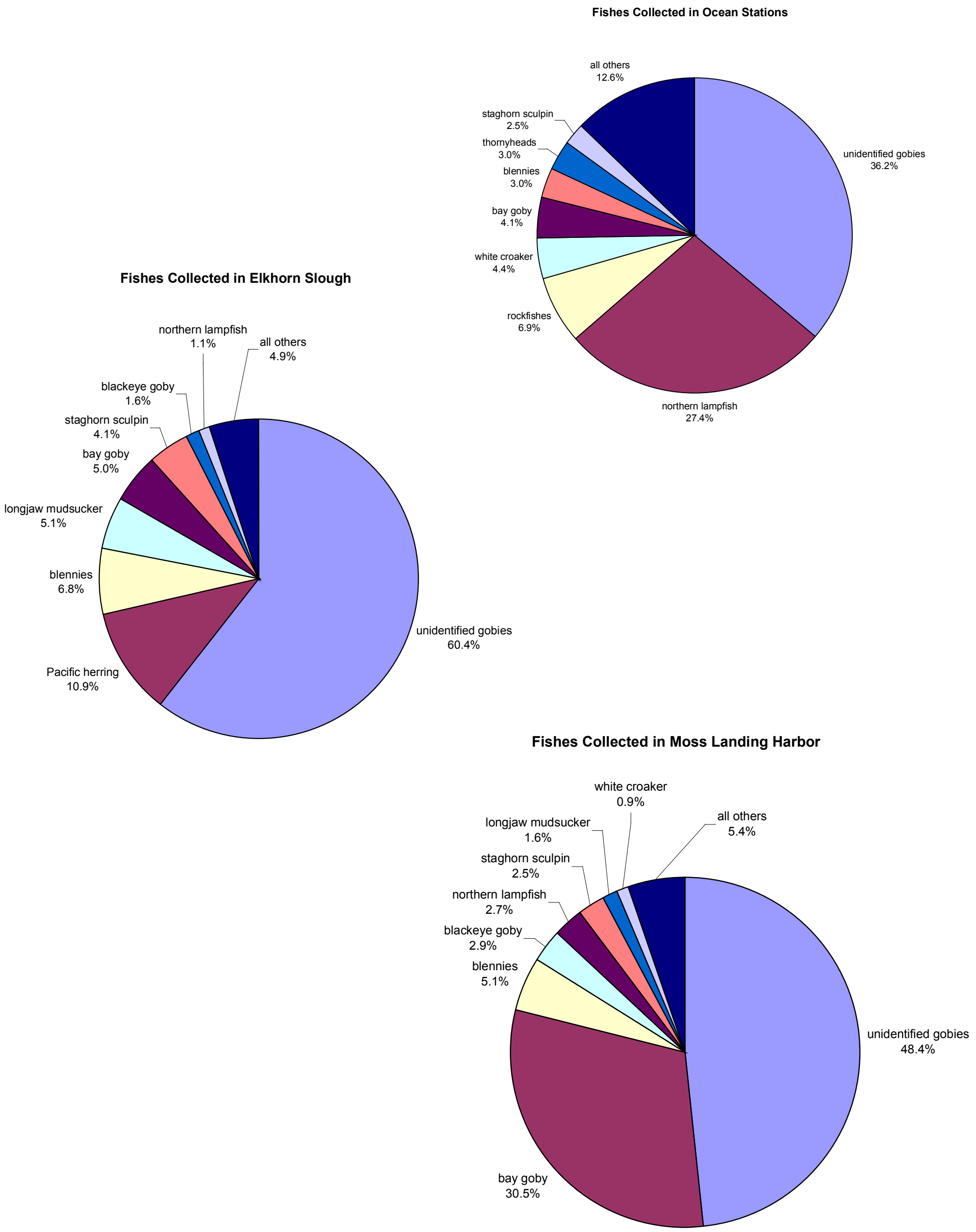


Figure 4-4. Percent composition of the most abundant larval fish taxa collected in source water surveys at Elkhorn Slough, Moss Landing Harbor, and Ocean areas: June 1999 through February 2000.

Mean source water concentrations (no./1,000 m^3) for all larval fishes for all source water surveys are presented in Table 4-7. Source water concentrations of the eight most abundant taxa collected in the entrainment surveys (Section 4-1) are discussed individually in Sections 4-3 through 4-10.

Mean source water concentrations (no./1,000 m^3) for all targeted crab species collected in source water surveys are presented in Table 4-7. Source water concentrations of the targeted crab species collected in the entrainment surveys (Section 4-1) are discussed individually in Sections 4-11 through 4-18.

Three species of cancer crab megalops comprised 100 percent of the total numbers of taxa collected in the Elkhorn Slough area (Figure 4-5). The taxa, listed in decreasing order of abundance were: hairy rock crab *Cancer jordani* (50 percent), red rock crab *Cancer productus* (25 percent), and yellow rock crab *Cancer anthonyi* (25 percent).

Species composition was more varied at the Moss Landing Harbor area. Five species of cancer crab megalops comprised 100 percent of the total numbers of taxa collected in the Moss Landing Harbor area (Figure 4-5). The taxa, listed in decreasing order of abundance were: hairy rock crab (36.4 percent), brown rock crab *Cancer antennarius* (34.7 percent), red rock crab (12.2 percent), yellow rock crab (8.2 percent), and slender rock crab *Cancer gracilis* (8.2 percent).

Five taxa of cancer crab megalops comprised 100 percent of the total numbers collected in the Ocean area (Figure 4-5). The taxa, listed in decreasing order of abundance were: hairy rock crab (66.9 percent), unidentified *Cancer* spp. (15.9 percent), brown rock crab (10.6 percent), slender rock crab (5.3 percent), and yellow rock crab (1.3 percent).

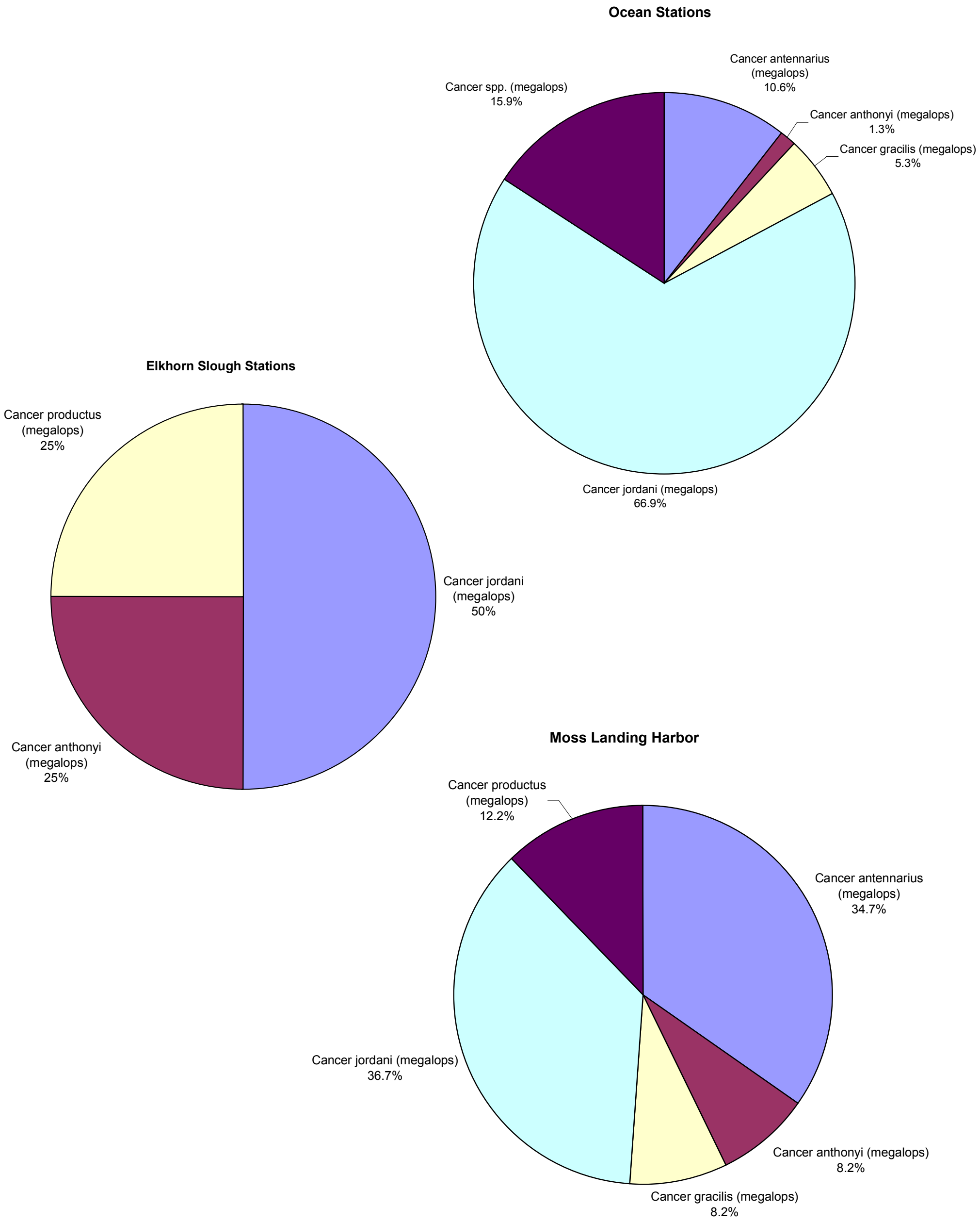


Figure 4-5. Percent composition of the most abundant megalopal cancer crab taxa collected in source water surveys at Elkhorn Slough, Moss Landing Harbor, and Ocean Areas: June 1999 through February 2000.

Table 4-7. Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa, *Cancer* spp. Megalops, and European Green Crab Megalops Collected in the Source Water in the Vicinity of the Moss Landing Power Plant: June 1999 through February 2000.

Taxon	Common Name	Count	Survey 1 June 17, 1999 Mean Den. (#/1000m3)						Survey 2 July 12, 1999 Mean Den. (#/1000m3)						Survey 3 August 12, 1999 Mean Den. (#/1000m3)					
			Kirby Park N = 4		Dairies N = 4		Harbor Bridge N = 4		Kirby Park N = 2		Dairies N = 4		Harbor Bridge N = 3		Kirby Park N = 4		Dairies N = 4		Harbor Bridge N = 4	
			Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.
Agonidae unid.	poachers	1																		
Ammodytes hexapterus	Pacific sand lance	547																		
Artedius spp.	sculpins	8																		
Atherinidae unid.	silversides	40			1	2.7														
Atherinopsis californiensis	jacksmelt	97																		
Bathylagus ochotensis	popeye blacksmelt	1																		
Bathymasteridae unid.	ronquils	2											1	4.5						
Blennioidei	blennies	1																		
Cebidichthys violaceus	monkeyface eel	75																		
Chaenopsidae unid.	tube blennies	1																		
Citharichthys sordidus	Pacific sanddab	13																		
Citharichthys stigmaeus	speckled sanddab	12																		
Clinocottus analis	wooly sculpin	2																		
Clupea pallasii	Pacific herring	683			2	6.2							1	5.7						
Clupeidae unid.	herrings	1																		
Clupeiformes	herrings and anchovies	11					1	4.3												
Coryphopterus nicholsi	blackeye goby	62	34	146.3	8	23.0							2	10.2					4	17.1
Cottidae unid.	sculpins	48			1	3.0														
Cottus asper	prickly sculpin	38																		
Engraulis mordax	northern anchovy	55																		
Genyonemus lineatus	white croaker	399																		
Gibbonsia spp.	clinid kelpfishes	1																		
Gillichthys mirabilis	longjaw mudsucker	214	45	182.0	22	61.6			12	141.0					2	10.1	1	4.8		
Gobiidae unid.	unidentified gobies	8,686	366	1571.8	146	414.3	7	33.7	72	845.7	12	49.2	12	58.3	14	57.4	27	137.3	12	53.2
Hexagrammidae unid.	greenlings	2																		
Hypsoblennius spp.	blennies	239	4	17.3	35	99.7	3	14.5	1	11.7	3	12.4	49	253.5	11	36.9	68	343.1		
larval fish - damaged	unidentified larval fishes	7																		
larval fish fragment	unidentified larval fishes	181									2	7.9	2	9.0						
larval/post-larval fish, unid.	unidentified larval fishes	12					1	4.3												
Lepidogobius lepidus	bay goby	1,861	2	7.9	2	5.7					1	5.0	5	24.9					1	4.4
Leptocottus armatus	Pacific staghorn sculpin	465																		
Leuresthes tenuis	California grunion	1																		
Liparis spp.	snailfishes	1																		
Oligocottus spp.	sculpins	1																		
Osmeridae unid.	smelts	216					1	6.0												
Oxylebius pictus	painted greenling	3																		
Paralichthyidae unid.	lefteye flounders & sanddabs	2																		
Parophrys vetulus	English sole	3																		
Pleuronectes bilineatus	rock sole	3																		
Pleuronectidae unid.	flounders	80																		
Pleuronectiformes unid.	flatfishes	27																		
Psettichthys melanostictus	sand sole	5																		
Scorpaenichthys marmoratus	cabezon	9																		
Sebastes aurora	aurora rockfish	1																		
Sebastes diploproa	splitnose rockfish	1																		
Sebastes jordani	shortbelly rockfish	3																		
Sebastes spp.	rockfishes	12																		
Sebastes spp. V	rockfishes	82																		
Sebastes spp. V_De	rockfishes	2																		
Sebastes spp. VD	rockfishes	58																		
Sebastolobus spp.	thornyheads	92																		
Stenobrachius leucopsarus	northern lampfish	630																		
Stichaeidae unid.	pricklebacks	1																		
Syngnathidae unid.	pipefishes	2																	1	4.1
Tarletonbeania crenularis	blue lanternfish	37																		
Xeneretmus latifrons	blackeye poacher	1																		
	FISH TOTALS:	15,038	451		217		13		85		18		72		27		96		18	
Cancer antennarius (megalops)	brown rock crab	17																		
Cancer anthonyi (megalops)	yellow rock crab	2																		
Cancer gracilis (megalops)	slender rock crab	10																		
Cancer jordani (megalops)	hairy rock crab	110																		
Cancer productus (megalops)	red rock crab	3																		
Cancer spp. (megalops)	unidentified cancer crabs	24																		
Carcinus maenas (megalops)	European green crab	1																		
	CRAB TOTALS:	167	0		0		0		0		0		0		0		0		0	

Table 4-7 (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa, Cancer spp. Megalops, and European Green Crab Megalops Collected in the Source Water in the Vicinity of the Moss Landing Power Plant: June 1999 through February 2000.

Taxon	Common Name	Survey 4 September 16, 1999 Mean Den. (#/1000m3)												Survey 5 October 14, 1999 Mean Den. (#/1000m3)											
		Kirby Park N = 4		Dairies N = 4		Harbor Bridge N = 4		Harbor Mouth N = 4		Ocean North N = 4		Ocean South N = 4		Kirby Park N = 4		Dairies N = 4		Harbor Bridge N = 4		Harbor Mouth N = 4		Ocean North N = 4		Ocean South N = 4	
		Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.
Agonidae unid.	poachers																								
Ammodytes hexapterus	Pacific sand lance																								
Artedius spp.	sculpins															1	5.7								
Atherinidae unid.	silversides																								
Atherinopsis californiensis	jacksmelt																								
Bathylagus ochotensis	popeye blacksmelt																								
Bathymasteridae unid.	ronquils																								
Blennioidei	blennies																								
Cebidichthys violaceus	monkeyface eel																								
Chaenopsidae unid.	tube blennies			1	6.3																				
Citharichthys sordidus	Pacific sanddab																								
Citharichthys stigmaeus	speckled sanddab																								
Clinocottus analis	wooly sculpin																								
Clupea pallasii	Pacific herring																								
Clupeidae unid.	herrings																								
Clupeiformes	herrings and anchovies																								
Coryphopterus nicholsi	blackeye goby			2	12.7											1	5.2					1	2.2		
Cottidae unid.	sculpins																					1	2.4	1	2.5
Cottus asper	prickly sculpin																								
Engraulis mordax	northern anchovy																					1	2.2		
Genyonemus lineatus	white croaker																							1	2.0
Gibbonsia spp.	clinid kelpfishes																								
Gillichthys mirabilis	longjaw mudsucker	2	12.6	2	10.8											6	32.1	3	16.2						
Gobiidae unid.	unidentified gobies	50	314.9	14	84.3			1	5.0			1	2.9	38	181.7	184	965.8	61	322.4	3	10.2			2	4.7
Hexagrammidae unid.	greenlings																								
Hypsoblennius spp.	blennies	8	53.7	9	55.5					2	5.1	1	2.9	3	17.3	25	126.9	8	44.9	3	10.3	3	6.9		
larval fish - damaged	unidentified larval fishes																								
larval fish fragment	unidentified larval fishes															2	9.2			1	2.9	1	2.6		
larval/post-larval fish, unid.	unidentified larval fishes																								
Lepidogobius lepidus	bay goby			31	198.8			1	6.9	3	7.1	1	2.3			31	158.6	48	254.3	1	3.4				
Leptocottus armatus	Pacific staghorn sculpin									1	2.3	1	2.9									2	4.7	1	2.2
Leuresthes tenuis	California grunion																								
Liparis spp.	snailfishes																								
Oligocottus spp.	sculpins																								
Osmeridae unid.	smelts					1	4.9	2	13.5																
Oxylebius pictus	painted greenling																								
Paralichthyidae unid.	lefteye flounders & sanddabs																								
Parophrys vetulus	English sole																								
Pleuronectes bilineatus	rock sole																								
Pleuronectidae unid.	flounders																								
Pleuronectiformes unid.	flatfishes																								
Psettichthys melanostictus	sand sole																								
Scorpaenichthys marmoratus	cabezon																								
Sebastes aurora	aurora rockfish																								
Sebastes diploproa	splitnose rockfish																								
Sebastes jordani	shortbelly rockfish																								
Sebastes spp.	rockfishes																								
Sebastes spp. V	rockfishes																								
Sebastes spp. V_De	rockfishes																								
Sebastes spp. VD	rockfishes																								
Sebastolobus spp.	thornyheads																								
Stenobrachius leucopsarus	northern lampfish																								
Stichaeidae unid.	pricklebacks																								
Syngnathidae unid.	pipefishes																								
Tarletonbeania crenularis	blue lanternfish																								
Xeneretmus latifrons	blackeye poacher																								
	FISH TOTALS:	60		59		1		4		6		4		41		250		120		8		9		5	
Cancer antennarius (megalops)	brown rock crab									1	2.3											4	10.8	1	2.0
Cancer anthonyi (megalops)	yellow rock crab																								
Cancer gracilis (megalops)	slender rock crab									2	5.6									1	3.6			2	4.5
Cancer jordani (megalops)	hairy rock crab									18	52.0	3	8.7					2	11.2	10	33.5	2	5.1	13	27.9
Cancer productus (megalops)	red rock crab																								
Cancer spp. (megalops)	unidentified cancer crabs									16	39.1											1	2.6	1	2.0
Carcinus maenas (megalops)	European green crab																								
	CRAB TOTALS:	0		0		0		0		37		3		0		0		2		11		7		17	

Table 4-7 (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa, *Cancer* spp. Megalops, and European Green Crab Megalops Collected in the Source Water in the Vicinity of the Moss Landing Power Plant: June 1999 through February 2000.

Taxon	Common Name	Survey 6 November 18, 1999 Mean Den. (#/1000m3)												Survey 7 December 29, 1999 Mean Den. (#/1000m3)											
		Kirby Park N = 4		Dairies N = 4		Harbor Bridge N = 4		Harbor Mouth N = 4		Ocean North N = 4		Ocean South N = 4		Kirby Park N = 2		Dairies N = 4		Harbor Bridge N = 4		Harbor Mouth N = 4		Ocean North N = 4		Ocean South N = 4	
		Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.
Agonidae unid.	poachers																								
Ammodytes hexapterus	Pacific sand lance																								
Artedius spp.	sculpins																								
Atherinidae unid.	silversides																								
Atherinopsis californiensis	jacksmelt													16	270.3										
Bathylagus ochotensis	popeye blacksmelt																								
Bathymasteridae unid.	ronquils																								
Blennioidei	blennies																								
Cebidichthys violaceus	monkeyface eel																								
Chaenopsidae unid.	tube blennies																								
Citharichthys sordidus	Pacific sanddab																							1	2.3
Citharichthys stigmaeus	speckled sanddab																								
Clinocottus analis	wooly sculpin																								
Clupea pallasii	Pacific herring													10	180.8										
Clupeidae unid.	herrings																								
Clupeiformes	herrings and anchovies																								
Coryphopterus nicholsi	blackeye goby	2	12.6																						
Cottidae unid.	sculpins					1	4.4			1	2.8							1	5.5			2	4.4	1	2.0
Cottus asper	prickly sculpin																								
Engraulis mordax	northern anchovy																								
Genyonemus lineatus	white croaker			1	4.9							2	4.8					2	10.8						
Gibbonsia spp.	clinid kelpfishes																								
Gillichthys mirabilis	longjaw mudsucker	8	44.9	3	15.3	5	31.6	7	26.4			1	2.3	1	12.7	6	55.8	2	11.5	1	4.6				
Gobiidae unid.	unidentified gobies	27	152.0	38	186.7	173	1064.9	127	490.6	15	32.2	6	12.6	23	399.6	102	844.9	30	166.8	79	335.7	8	19.5	1	2.3
Hexagrammidae unid.	greenlings																								
Hypsoblennius spp.	blennies					1	7.3																		
larval fish - damaged	unidentified larval fishes																								
larval fish fragment	unidentified larval fishes	1	5.6					3	11.4	1	2.1	4	9.6									2	5.1	2	5.0
larval/post-larval fish, unid.	unidentified larval fishes																								
Lepidogobius lepidus	bay goby	1	5.6	1	4.9	20	116.2	12	45.8	4	8.3	4	9.0			3	24.7			6	25.6			1	2.7
Leptocottus armatus	Pacific staghorn sculpin							1	4.6	4	8.3	2	4.5	13	184.9	13	124.0			14	62.7	4	10.5	1	2.7
Leuresthes tenuis	California grunion																								
Liparis spp.	snailfishes																								
Oligocottus spp.	sculpins																								
Osmeridae unid.	smelts																								
Oxylebius pictus	painted greenling																								
Paralichthyidae unid.	lefteye flounders & sanddabs															1	6.4							1	2.7
Parophrys vetulus	English sole																								
Pleuronectes bilineatus	rock sole																								
Pleuronectidae unid.	flounders																								
Pleuronectiformes unid.	flatfishes																								
Psettichthys melanostictus	sand sole																								
Scorpaenichthys marmoratus	cabezon																								
Sebastes aurora	aurora rockfish																								
Sebastes diploproa	splitnose rockfish																					1	2.6		
Sebastes jordani	shortbelly rockfish																								
Sebastes spp.	rockfishes																							1	2.0
Sebastes spp. V	rockfishes																							4	10.5
Sebastes spp. V_De	rockfishes																								
Sebastes spp. VD	rockfishes																					2	5.1	5	11.4
Sebastolobus spp.	thornyheads																								
Stenobrachius leucopsarus	northern lampfish											1	2.3			1	7.0	2	11.5	11	46.7	17	40.3	25	57.2
Stichaeidae unid.	pricklebacks																								
Syngnathidae unid.	pipefishes	1	7.1																						
Tarletonbeania crenularis	blue lanternfish																			2	8.0			1	2.7
Xeneretmus latifrons	blackeye poacher																								
	FISH TOTALS:	40		43		200		150		25		20		63		126		37		113		36		44	
Cancer antennarius (megalops)	brown rock crab									1	2.8											8	19.4		
Cancer anthonyi (megalops)	yellow rock crab																							2	4.2
Cancer gracilis (megalops)	slender rock crab																					2	4.2	1	2.2
Cancer jordani (megalops)	hairy rock crab																			1	4.4	53	124.0		
Cancer productus (megalops)	red rock crab																								
Cancer spp. (megalops)	unidentified cancer crabs																					6	14.4		
Carcinus maenas (megalops)	European green crab																							1	2.7
	CRAB TOTALS:	0		0		0		0		1		0		0		0		0		1		69		4	

Table 4-7 (continued). Mean Concentrations (#/1,000 m^3) of all Larval Fish Taxa, *Cancer* spp. Megalops, and European Green Crab Megalops Collected in the Source Water in the Vicinity of the Moss Landing Power Plant: June 1999 through February 2000.

Taxon	Common Name	Survey 8 January 20, 2000 Mean Den. (#/1000m3)												Survey 13 February 24, 2000 Mean Den. (#/1000m3)											
		Kirby Park N = 4		Dairies N = 4		Harbor Bridge N = 4		Harbor Mouth N = 4		Ocean North N = 4		Ocean South N = 4		Kirby Park N = 4		Dairies N = 4		Harbor Bridge N = 4		Harbor Mouth N = 4		Ocean North N = 4		Ocean South N = 4	
		Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.	Count	Den.
Agonidae unid.	poachers																								
Ammodytes hexapterus	Pacific sand lance							1	4.2			1	2.7									21	50.1	1	1.8
Artedius spp.	sculpins							1	7.5							2	7.4								
Atherinidae unid.	silversides													11	47.0	1	3.5			1	4.7				
Atherinopsis californiensis	jacksmelt			1	4.1									3	13.7	3	8.4								
Bathylagus ochotensis	popeye blacksmelt																							1	1.8
Bathymasteridae unid.	ronquils									1	2.1														
Blennioidei	blennies																								
Cebidichthys violaceus	monkeyface eel																	1	6.4			3	6.0		
Chaenopsidae unid.	tube blennies																								
Citharichthys sordidus	Pacific sanddab																	1	3.8					2	3.9
Citharichthys stigmaeus	speckled sanddab															1	4.6			2	8.8	5	9.6	1	2.8
Clinocottus analis	wooly sculpin																			2	9.4				
Clupea pallasii	Pacific herring	5	29.2	4	14.8	1	5.7	3	15.2					331	1471.5	3	10.9	9	47.8	7	30.7	1	2.2		
Clupeidae unid.	herrings	1	4.7																						
Clupeiformes	herrings and anchovies																	1	5.1			1	1.8		
Coryphopterus nicholsi	blackeye goby															2	9.3			2	9.0				
Cottidae unid.	sculpins					1	6.6	1	7.5									1	3.8	1	4.7				
Cottus asper	prickly sculpin													1	4.7			5	27.4	3	13.5	1	1.8	1	2.1
Engraulis mordax	northern anchovy							1	6.1	1	2.3	1	2.0	12	52.5							1	2.4		
Genyonemus lineatus	white croaker															5	24.4	13	69.1	30	135.8	35	82.4	23	49.0
Gibbonsia spp.	clinid kelpfishes			1	7.1																				
Gillichthys mirabilis	longjaw mudsucker	3	17.2			1	6.6	2	11.6			1	2.0	37	163.4	9	26.6	2	10.2	3	12.5				
Gobiidae unid.	unidentified gobies	34	191.8	55	309.6	64	388.2	73	423.1	1	2.3	19	37.8	207	918.2	68	255.3	193	945.6	283	1256.7	23	51.3	80	178.0
Hexagrammidae unid.	greenlings	1	4.4																						
Hypsoblennius spp.	blennies																			1	4.1				
larval fish - damaged	unidentified larval fishes											1	2.2												
larval fish fragment	unidentified larval fishes	1	4.7					5	23.5									9	43.8	7	31.0	7	14.9	13	28.3
larval/post-larval fish, unid.	unidentified larval fishes																			1	4.7			1	1.8
Lepidogobius lepidus	bay goby	3	16.0	7	32.2	4	25.2	20	129.7			14	27.7			3	10.9	4	21.7	4	18.5	8	16.7	1	2.8
Leptocottus armatus	Pacific staghorn sculpin	20	93.3			3	19.7	1	6.1	8	19.4			59	252.1	21	74.7	10	45.2	6	27.0	4	8.4	1	2.2
Leuresthes tenuis	California grunion																								
Liparis spp.	snailfishes																								
Oligocottus spp.	sculpins																								
Osmeridae unid.	smelts					2	12.0	3	15.9							1	4.6	9	45.1	10	45.1	1	1.8		
Oxylebius pictus	painted greenling																								
Paralichthyidae unid.	lefteye flounders & sanddabs																								
Parophrys vetulus	English sole																								
Pleuronectes bilineatus	rock sole																								
Pleuronectidae unid.	flounders															5	24.8	11	52.9	16	73.1	10	26.8	5	10.8
Pleuronectiformes unid.	flatfishes	1	4.4					3	17.2			2	4.0			1	5.0					6	10.8	3	6.3
Psettichthys melanostictus	sand sole															1	4.6								
Scorpaenichthys marmoratus	cabezon																								
Sebastes aurora	aurora rockfish																							1	2.1
Sebastes diploproa	splitnose rockfish																								
Sebastes jordani	shortbelly rockfish									2	4.8											1	2.4		
Sebastes spp.	rockfishes									6	14.4							1	6.4	1	4.3			3	5.8
Sebastes spp. V	rockfishes			1	3.1					7	16.1	5	10.8			1	5.0	1	6.1	1	4.9	20	42.9	39	86.8
Sebastes spp. V_De	rockfishes					1	5.7													1	4.3				
Sebastes spp. VD	rockfishes							2	9.7	19	44.7	3	6.9					1	6.1	2	8.2	13	26.5	9	20.4
Sebastolobus spp.	thornyheads																	10	51.2	14	62.6	24	50.0	24	52.0
Stenobrachius leucopsarus	northern lampfish															5	20.9	28	148.4	66	293.7	311	647.6	138	289.9
Stichaeidae unid.	pricklebacks																								
Syngnathidae unid.	pipefishes																								
Tarletonbeania crenularis	blue lanternfish																	2	11.5	6	26.0	14	30.2	12	26.1
Xeneretmus latifrons	blackeye poacher											1	2.0												
	FISH TOTALS:	69		69		77		116		45		48		661		132		312		470		510		359	
Cancer antennarius (megalops)	brown rock crab																			1	4.7				
Cancer anthonyi (megalops)	yellow rock crab																								
Cancer gracilis (megalops)	slender rock crab																								
Cancer jordani (megalops)	hairy rock crab																			1	4.7				
Cancer productus (megalops)	red rock crab																								
Cancer spp. (megalops)	unidentified cancer crabs																								
Carcinus maenas (megalops)	European green crab																								
	CRAB TOTALS:	0		0		0		0		0		0		0		0		0		2		0		0	

4.3 Gobiidae: Introduction

Gobies belong to a successful family (Gobiidae) of small, demersal fishes that are found worldwide in shallow tropical and subtropical environments. The family contains around 1,875 species in 212 genera (Nelson, 1994; Moser, 1996). The Family Gobiidae is second only to the Family Cyprinididae (minnows) in total numbers of species (Moyle and Cech, 1988). Twenty-one goby species from 16 genera occur in the California Cooperative Oceanic Fisheries Investigations (CalCOFI) study area, from the northern California border to south of Baja California (Moser, 1996).

Members of the goby family share a variety of distinguishing characteristics. Their body shape is elongate and can be either somewhat compressed or depressed (Moser, 1996). Most members of the family lack both a lateral line and swim bladder (Moyle and Cech, 1988). Gobies generally have two dorsal fins, the first consisting of 2 to 8 flexible spines and the second containing a spine and several segmented rays (Moyle and Cech, 1988; Moser, 1996). Their caudal fin is rounded and their pelvic fins are typically joined to form a cup-like disc (Moser, 1996). The eyes of most gobies are relatively large and are a dominant feature of their blunt heads (Moyle and Cech, 1988). Goby species are extremely variable in coloration. They range from the drab, cryptically colored species that inhabit mudflats to the striking, brightly colored species of tropical and subtropical reefs (Moser, 1996).

One of the most important characteristics of the goby family is their small size. The smallest known vertebrate, which is mature at 8 to 10 mm (0.3 to 0.4 in.), is a goby species *Trimmatom nanus* from the Chagos Islands in the Indian Ocean (Moyle and Cech, 1988). The yellowfin goby *Acanthogobius flavimanus*, an introduced species that is native to China, is the largest goby species found along the California coast. It reaches a maximum total length (TL) of around 241 mm (9.5 in.) (Miller and Lea, 1972). Due to their size and evolved tolerances for a variety of environmental conditions, gobies have been able to colonize habitats that are inaccessible to most other fishes (Moyle and Cech, 1988). These include cracks and crevices in coral reefs, invertebrate burrows, mudflats, mangrove swamps, freshwater streams on oceanic islands and inland seas and estuaries (Moyle and Cech, 1988).

Gobies generally occur in shallow marine habitats, however many members of the family are euryhaline and are able to tolerate very low salinities and even freshwater. Gobies are often the principal freshwater fish species on oceanic islands and are common in many of the rivers and streams in Asia (Moyle and Cech, 1988). A goby species *Pandaka pygmaea* from Luzon (Philippines), which is mature at 10 to 12 mm (0.4 to 0.5 in.), is the world’s smallest freshwater fish. A number of goby species also have the ability to survive out of the water by “breathing” air. The longjaw mudsucker *Gillichthys mirabilis* can survive for days out of water if kept moist, and the mudskipper *Periopthalamus* spp. regularly leaves the water to forage for terrestrial insects among mangrove roots and exposed rocks (Moyle and Cech, 1988). Gobies eat a variety of larval, juvenile, and adult crustaceans, mollusks, and insects. Many will also eat small fishes, fish eggs, and fish larvae. Gobies from the genus *Gobisoma* are known to "clean" other fishes of ectoparasites. In what could be defined as a parasitic relationship, one group of gobies feeds on the tube feet of their sea urchin hosts (Teylaud, 1971).

Gobies are oviparous and produce demersal eggs which are generally elliptical in shape (Moser, 1996), typically adhesive, and are attached to the nest substrate at one end. Parental care, often provided by the male, is common in the family (Moser, 1996). Hatched larvae are planktonic. The duration of the planktonic stage varies greatly within the family. Larval gobiids are distinctive and not easily confused with other fish larvae. Exceptions include certain life stages of eleotrids and scarids (Moser, 1996).

4.3.1 Unidentified Gobies

Identification of larval gobiids to the species level is difficult. Larval gobies collected during MLPP entrainment sampling that could not be identified to the species level were left at the family level (Gobiidae) and are probably composed of some combination of the following species: arrow goby *Clevelandia ios*, cheekspot goby *Ilypnus gilberti*, and the yellowfin goby *Acanthogobius flavimanus*. At certain larval stages, bay goby *Lepidogobius lepidus* may share similar taxonomic characters making it difficult to separate from the other species, especially when the specimens are not in good condition.

Myomere counts and dorsal pigmentation characteristics can be used to identify many larvae to the species level (Moser, 1996). A number of species cannot be separated unequivocally during certain larval stages (Moser, 1996). The arrow goby *Clevelandia ios*, cheekspot goby *Ilypnus gilberti*, and the shadow goby *Quietula y-cauda* cannot be differentiated during any larval stage (Moser, 1996). However, the known range of the shadow goby *Q. y-cauda* extends only as far north as Morro Bay in central California. Adult shadow gobies were not found in a recent study of fishes in the vicinity of the MLPP (Lindquist, 1998). Brothers (1975) reported difficulty in separating arrow goby from cheekspot goby that were less than 65 mm (2.6 in.) in length.

The arrow goby *C. ios* and the cheekspot goby *I. gilberti* have overlapping ranges and occupy similar habitats. Both species inhabit burrows in mud flats and other shallow regions of bays and estuaries (Miller and Lea, 1972). The fecundity of the arrow goby (750 to 1,000 eggs) and the cheekspot goby (250 to 1,800 eggs) are similar (Wang, 1986). Eggs are demersal and adhesive, with filaments for anchoring to substrates (Wang, 1986). No fecundity information is available for the shadow goby. The northern range of the cheekspot goby extends to Tomales Bay (Miller and Lea, 1972). Arrow goby occupy the most extensive range (of the three), occurring from the

Gulf of California to Vancouver Island, British Columbia (Miller and Lea, 1972). Arrow goby are common in the Moss Landing-Elkhorn Slough area and probably account for a majority of the unidentified larval gobies collected during MLPP entrainment sampling. The cheekspot goby has been documented in the area and may compose a portion of the Gobiidae category.

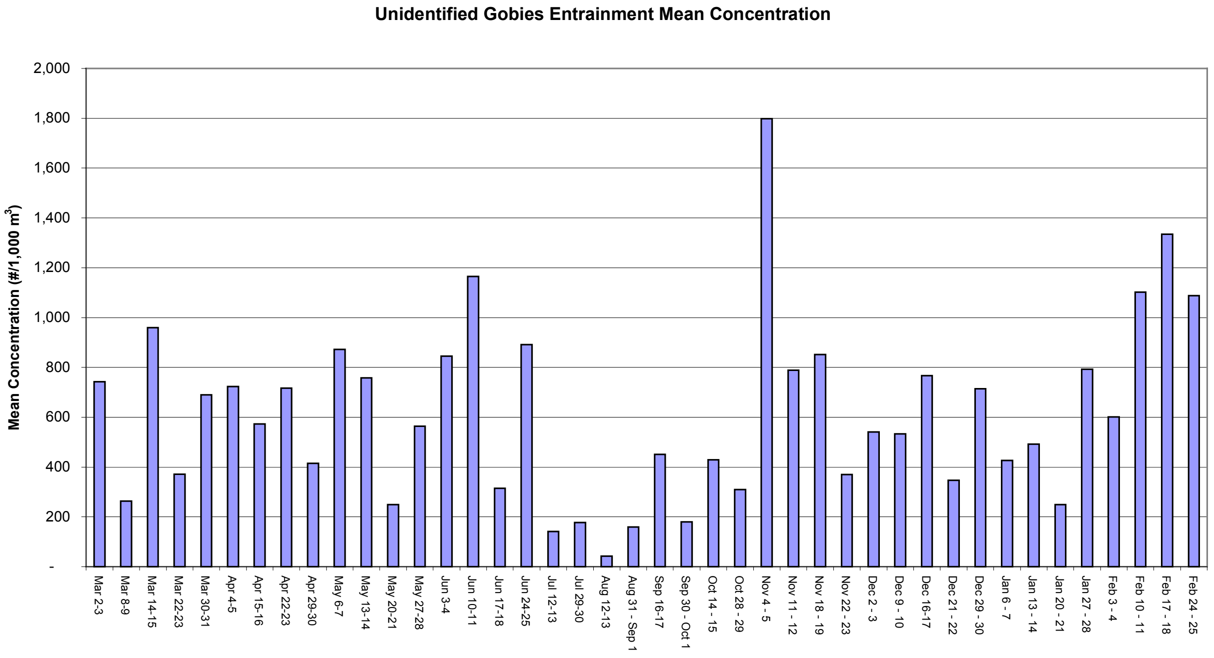
Since it appears that arrow goby may account for a large portion of the larvae identified as Gobiidae, its demography will be used to estimate entrainment effects. Brothers (1975) estimated a two-month mortality for arrow goby larvae of 98.3 percent. Combining this estimate with species-specific fecundity and an assumption of stable age distribution, allowed us to calculate the number of adults potentially affected by larval entrainment mortality.

Endangered tidewater goby *Eucyclogobius newberryi* adults were recently collected in Bennett Slough in October 1999 (M. Sazaki, CEC, pers. comm.). Larval tidewater goby can be distinguished from other gobies and none were collected during any entrainment or source water surveys at MLPP.

4.3.2 Unidentified goby results (53.2 percent)

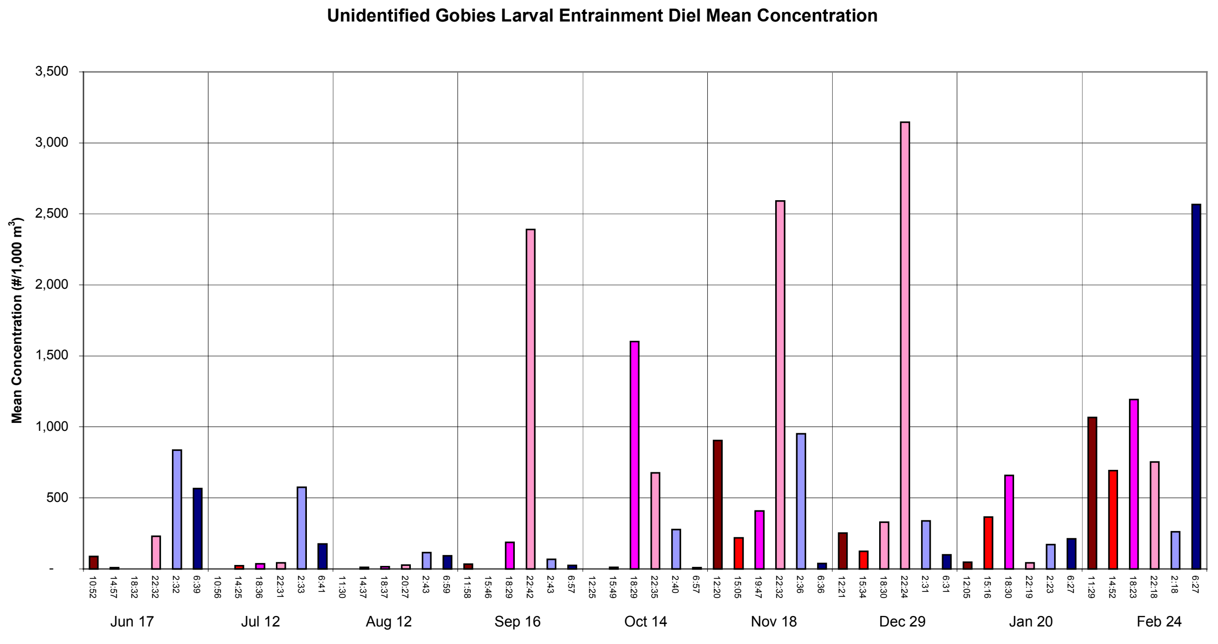
Unidentified larval gobies comprised 53.2 percent of the total number of fishes collected in entrainment samples from the new CC units intake (Figure 4-1). They were collected in all entrainment surveys from March 2, 1999 through February 24, 2000 from in front of the intake of new CC units (Figure 4-6). Peak concentration (1,799/1,000 m^3) occurred on November 4, 1999 and the lowest concentration (43/1,000 m^3) occurred on August 12, 1999.

The diel distributions were plotted for concentrations of larval unidentified gobies collected in front of the new combined-cycle units intake (Figure 4-7). We analyzed only the entrainment surveys that coincided with the source water surveys from June 1999 through February 2000. Unidentified gobies were typically collected in highest concentrations during the nighttime between 2200 and 0300 hours PST except for the October 1999, and January and February 2000 surveys. In October 1999 and January 2000, the peak diel concentration occurred after sunset at approximately 1830 hours PST. In January 2000, the peak diel concentration occurred during daylight at 1035 hours, and in February 2000 the peak occurred at dawn (0627 hours).



Note: All data are preliminary.

Figure 4-6. Mean survey concentrations (#/1,000 m^3) of larval unidentified gobies at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

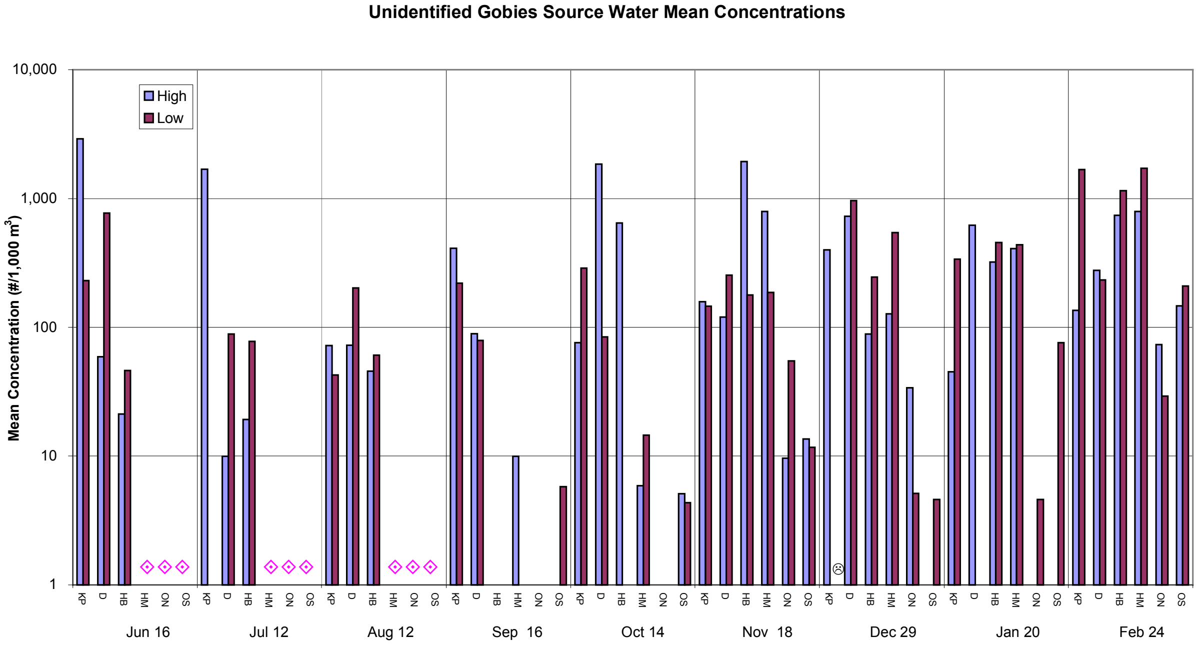


Note: These entrainment surveys were conducted at the same time as the source water surveys. Data are preliminary.

Figure 4-7. Concentrations (#/1,000 m^3) of larval unidentified gobies at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Larval unidentified gobies were the most abundantly collected taxa from the Elkhorn Slough, Moss Landing Harbor, and the Ocean areas. As previously stated, adults of both arrow (*C. ios*) and cheekspot (*I. gilberti*) gobies and have been documented in the area. It is likely that some of these unidentified gobies are represented by these species, although the larval forms at certain stages cannot be distinguished from one another. Mean concentrations (#/1,000 m^3) of unidentified gobies for all stations, by tidal cycle are presented in Figure 4-8.

Unidentified gobies comprised 60 percent of the total larval fishes collected in the Elkhorn Slough area, 48 percent in the Moss Landing Harbor area, and 36 percent in the Ocean area from June 1999 through February 2000. Unidentified gobies were collected every month (Figure 4-8). They were collected from all stations sampled from June through December 1999 except in September and October 1999, when they did not occur at the Harbor Bridge (September only) and Ocean North stations. Peaks in concentrations for both the low tides and high tides occurred in the Elkhorn Slough area; high tide concentrations peaked (2,913/1,000 m^3) in Kirby Park in June 1999 and the low tide peak concentration (1,682/1,000 m^3) occurred at the Kirby Park in February 2000. Unidentified gobies were collected at both high and low tides from all stations in November 1999 and February 2000. (Figure 4-8).



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

◇ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-8. Source water concentrations (#/1,000 m^3) of larval unidentified gobies at six stations near Moss Landing Power Plant: June 1999 through February 2000.

The Harbor Mouth, Ocean North, and Ocean South stations were not sampled in June, July, or August. Generally concentrations of undentified gobies were low at the Ocean Stations. The Ocean North Station had no unidentified gobies collected in September and October and concentrations of 73/1,000 m^3 were reached in February 2000 during high tide. Unidentified gobies were collected at the Ocean South Station in low concentrations (less than 15/1,000 m^3) during the September, October, November, and December surveys during high tide. In January and February 2000, concentrations increased at the Ocean South Station to a peak of 209/1,000 m^3 during a low tide on February 24, 2000.

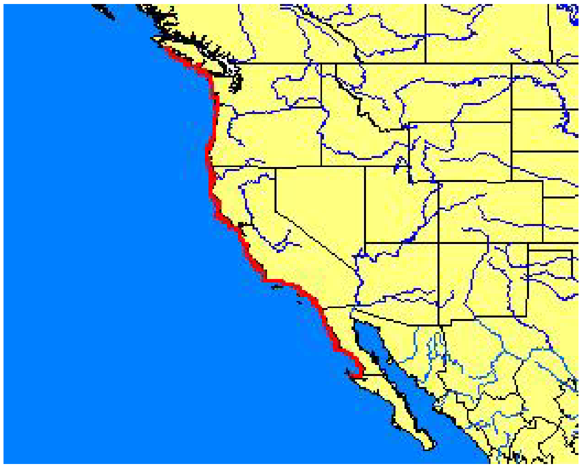
Data from the source water surveys show two seasonal peaks in unidentified goby concentrations. The highest concentration in the Elkhorn Slough stations occurred at Kirby Park in June 1999 (2,913/1,000 m^3) during high tide. Other high concentrations occurred during a high tide at the Harbor Bridge Station in November 1999 (1,940/1,000 m^3) and at a low tide (concentration = 1,721/1,000 m^3) in February 2000. These distinct seasonal peaks may indicate spawning by two species of goby. The peak concentration at Kirby Park also coincided with a peak in bay goby concentrations. It is possible that these unidentified gobies may be bay goby that were too small to identify to species. Similarities in concentration increases between bay goby and unidentified gobies also occurred in November at the Harbor Bridge, Harbor Mouth, Ocean North, and Ocean South stations.

Unidentified gobies were the second most abundantly entrained larval fishes collected in the first entrainment sampling program from November 1978 through March 1980 (PG&E, 1983). Taxonomic separations were not made within the Family Gobiidae except for longjaw mudsucker. It was thought that these unidentified gobies were probably arrow goby, bay goby, and yellowfin goby *Acanthogobius flavimanus*. Highest concentrations of 1,200/1,000 m^3 were collected in January 1980 at Units 1 through 5 (PG&E, 1983).

4.4 Bay Goby

Photographer: Neil McDaniel

Lepidogobius lepidus



Distribution Map for Bay Goby

Range: From Cedros Island, Baja California to Vancouver Island, British Columbia.

Life History: Size: to 108 mm (4.25 in.); age at maturity: one to two years old; fecundity: limited information available; lifespan: seven plus years.

Habitat: Intertidal mudflats, shallow pools.

Fishery: None.

The bay goby *Lepidogobius lepidus* is a common bottom-dwelling inhabitant of bays and estuaries along the Pacific coast of North America. They range from Vancouver Island, British Columbia to Cedros Island, Baja California (Miller and Lea, 1972). Bay goby were the most abundant goby species collected between 1980 to 1992 during trawl surveys conducted in San Francisco Bay by the California Department of Fish and Game (CDFG). The bay goby is generally considered a shallow-water marine species but may occur on mud and mud-sand substrates down to depths of 61 m (200 ft.) (Miller and Lea, 1972). They are common on intertidal mudflats where they remain in invertebrate burrows and shallow pools when the tide is out (Grossman, 1979). Like many marine-estuarine species they are tolerant of variations in salinity and temperature. During population monitoring studies in the San Francisco Bay-

Estuary bay goby occasionally (during periods of low Delta outflow) moved from marine waters, upstream through the Carquinez Straits into the lower salinity waters of Suisun Bay (CDFG, 1999).

The bay goby is a relatively small, elongate species that reaches a total length (TL) of about 108 mm (4.25 in.) (CDFG, 1999). Bay goby vary from light olive-green to tan or brown in color with dark reddish-brown or brown dorsal mottling. Ventrally they have a uniform lighter coloration. They generally have a black-edged first dorsal fin. Scales are small and cover the body and posterior portions of the head (Hart, 1973). They have a moderate-sized terminal mouth and a blunt snout (Hart, 1973). As with other goby species their pelvic fins are fused, forming a hollow cone. Bay goby are reported to live for 7 years or more, which is considered unusual longevity for a small fish species (Grossman, 1979). Life span estimates of 2 to 3 years have been derived from length frequency data collected by CDFG.

Based on differences in ova size/development from fish collected during April and May off Hunters Point Power Plant in San Francisco Bay and in Moss Landing Harbor, bay goby have been characterized as asynchronous multiple spawners (Wang, 1986). Female bay goby appeared to become reproductively mature at around 40 mm (1.6 in.) (Grossman, 1979). With the exception of a few gobies that mature within their first year, most individuals within a cohort do not become reproductively mature until their second year (Wang, 1986). Spawning occurred in Morro Bay from September through March, with peak activity occurring from January to March (Grossman, 1979). Grossman (1979) suggested that the timing of reproduction in bay goby may be highly variable. Little information about the details of bay goby spawning behavior exists in current literature. Because bay gobies use invertebrate burrows for predator avoidance and to stave-off dehydration during low tides it is thought that the species, like many other goby species, may also use burrows for spawning (Grossman, 1979; Wang, 1986). No fecundity information is available for bay goby. Eggs are demersal, and spherical/elliptical in shape with an adhesive anchoring point (Wang, 1986).

Newly hatched larvae are small (3 mm [0.12 in.] or less) and nearly transparent (Wang, 1986). Literature suggests that bay goby have a planktonic life phase of 3 to 4 months (Grossman, 1979; Wang, 1986). A 3 to 4 month estimate for the pelagic phase corresponded well with the recruitment models (based on gonadal maturity index data) for the species developed by Grossman (1979). This estimate also corresponded with the first appearance of settled larvae in Morro Bay, California during 1977. Bay goby larvae occur sympatrically with the larvae of arrow goby *Clevelandia ios*, cheekspot goby *Ilypnus gilberti* and yellowfin goby *Acanthogobius flavimanus* in San Francisco Bay and with arrow goby *C. ios* and shadow goby *Quietula y-cauda* in Morro Bay (Wang, 1986; Grossman, 1979). In a study by Wang (1986) most larval bay gobies were collected in San Francisco Bay from November through May, with peak numbers occurring in April and May. The greatest concentrations of larval bay gobies within the San

Francisco Bay system appeared to be concentrated between the Golden Gate Bridge and Angel Island (Wang, 1986). At about 25 mm TL (0.98 in.) bay goby larvae settle out of the plankton layers to begin a demersal existence. A leopard-spot-like pattern of melanophores forms above the lateral line in juveniles around the time they descend to the bottom (Grossman, 1979). In addition to this cryptic coloration, juveniles (and adults) occupy the burrows of blue mud shrimp *Upogebia pugettensis*, geoduck clams *Panope generosa* and other burrowing animals for shelter and predator avoidance (Grossman, 1979).

No species-specific larval survivorship estimates were available for bay goby. However, Brothers (1975) calculated larval mortality over two-months, post-hatching for three sympatric gobiids (arrow goby, cheekspot goby, and shadow goby) from Mission Bay, California. These estimates were used to approximate bay goby mortality for early life stages as well as post-settlement juvenile and adult stages. Lack of species-specific fecundity data precluded estimation of *FH* for this species, but substituting survivorship from these closely related species for larval, juvenile, and adult stages allowed us to project future losses of equivalent adults.

Juvenile bay goby feed on a variety of small crustaceans including copepods and amphipods, as well as some detrital material (Wang, 1986). Growth is initially rapid, with 50 percent of their total growth (length) occurring within the first 2 years (Grossman, 1979). Following this period of rapid growth, increases in length slow to about 6 mm (0.24 in.) per year (Grossman, 1979). The diet of adult bay gobies is not detailed in current literature but probably consists of many of the same items consumed by sympatric goby species, including small crustaceans, mollusks, larval fishes, and fish and invertebrate eggs.

Bay goby are thought to be an important food item in the diet of a variety of vertebrate and invertebrate predators. Their abundance, small size, and long planktonic life make bay goby larvae an important link in the food web of bay/estuarine systems (Wang, 1986). Their abundance as juveniles and adults suggests that they remain an important forage species throughout all life stages. The Pacific staghorn sculpin *Leptocottus armatus* and California halibut *Paralichthys californicus* are among the many fish predators of adult bay goby (Brothers, 1975). It is also assumed that many of the elasmobranch species (sharks and rays) that inhabit estuarine systems prey on bay gobies (Grossman, 1979). A predatory opisthobranch species *Navanax intermis* is also a documented predator (Paine, 1963). Wading and "probe feeding" birds are thought to regularly prey on bay gobies living on intertidal mudflats (Reeder, 1951). Bird species like marbled godwits *Limosa fedoa* and willets *Catoptrophorus semipalmatus* are abundant on exposed tidal flats and probably consume a great number of bay goby. Terns *Sterna* spp. are also thought to be among the avian predators of the bay goby (Grossman, 1979). Due to their small size, bay goby are not harvested commercially for human consumption or targeted by recreational anglers (Wang, 1986). There is no mention in current literature of their harvest or use as bait, although they would probably be an effective bait for many species.

4.4.1 Bay goby results (30.4 percent)

Bay goby comprised 30.4 percent of the total numbers of larval fishes collected in entrainment surveys at the new CC units intake (Figure 4-1). They were collected in all entrainment surveys from March 2, 1999 through February 24, 2000 from in front of the intake of the CC units (Figure 4-9). Concentrations were typically below 200/1,000 m^3 for from March 1999 through mid-October 1999. Peak concentration (2,668/1,000 m^3) occurred on November 18, 1999 and the lowest concentration (22/1,000 m^3) occurred on May 6, 1999. From November 22, 1999 through February 24, 2000, concentrations ranged from a low of 152/1,000 m^3 to a high of 906/1,000 m^3 (Figure 4-9).

The diel distributions were plotted for concentrations of bay goby collected in front of the new combined-cycle units intake from June 1999 through February 2000 (Figure 4-10). We analyzed only the entrainment surveys that coincided with the source water surveys. Bay gobies were typically collected (8 out of 9 surveys) in highest concentrations during the nighttime between 1800 and 0300 hours PST. In February 2000 the peak diel concentration occurred at dawn at 0627 hours.

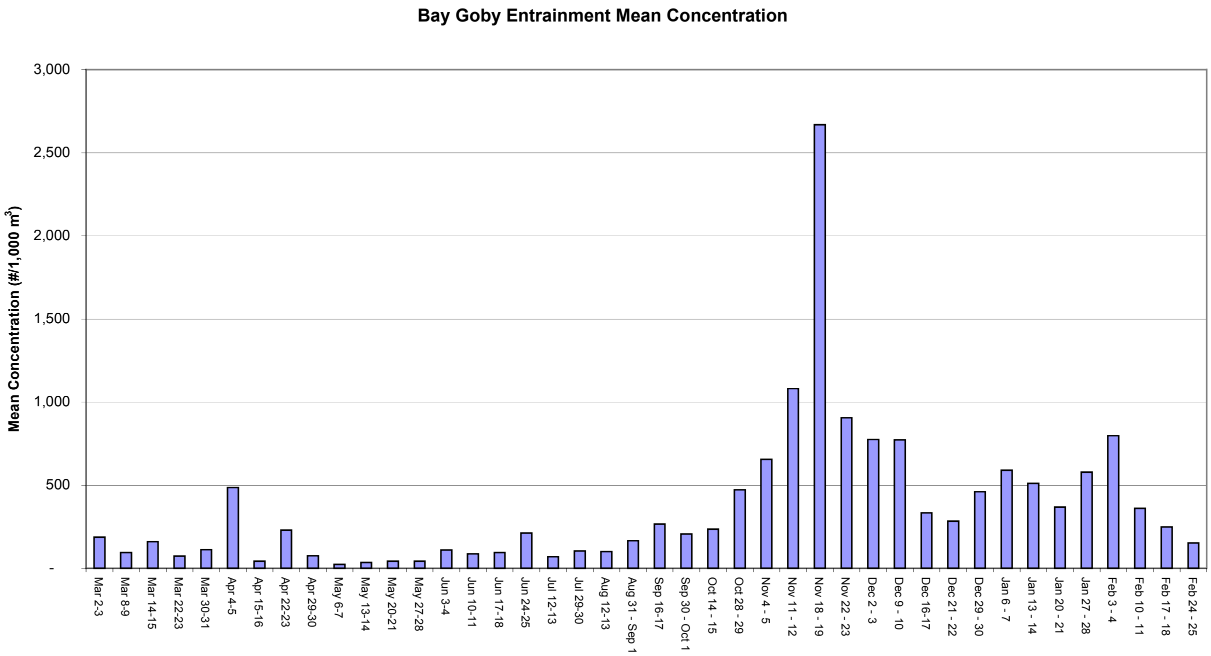
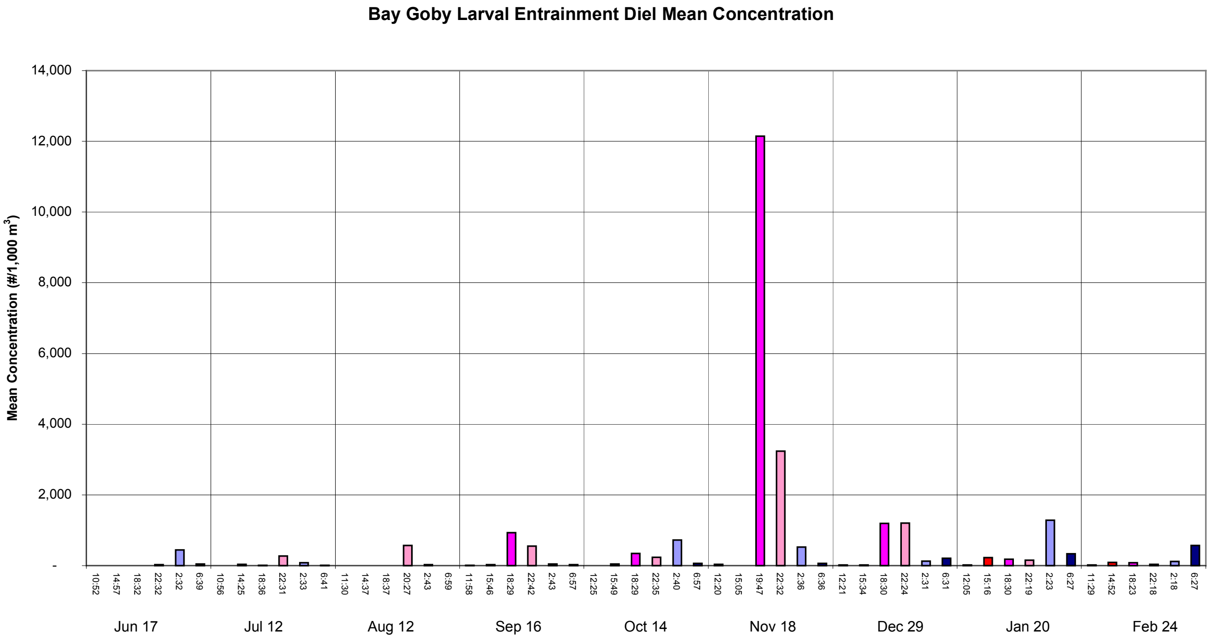


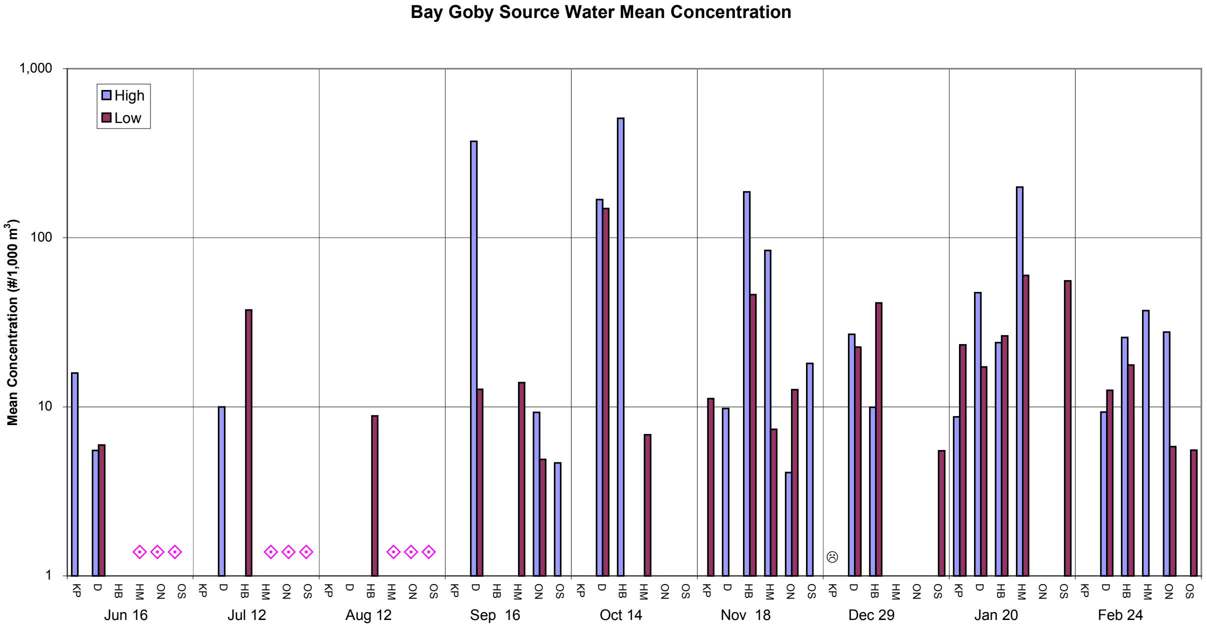
Figure 4-9. Mean survey concentrations (#/1,000 m^3) of larval bay goby at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.



Note: these entrainment surveys were conducted coincidentally with source water surveys.

Figure 4-10. Concentrations (#/1,000 m^3) of larval bay goby at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Bay goby comprised 5.0 percent of the total fishes collected in the Elkhorn Slough area, 30.5 percent in the Moss Landing Harbor area, and 4.1 percent in the Ocean area from June 1999 through February 2000 (Figure 4-4). Bay goby were collected in all surveys (Figure 4-11). They were also collected at all stations in November. The highest concentrations occurred at high tides in September, October, November 1999, and January 2000. Generally peak concentrations occurred during high tides except in August and December. The highest concentration (509/1,000 m^3) occurred at high tide in October at the Harbor Bridge station.



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

◇ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-11. Source water concentrations (#/1,000 m^3) of larval bay goby at six stations near Moss Landing Power Plant: June 1999 through February 2000.

Sub-samples of bay goby larvae collected from the source water surveys and the new combined-cycle intake surveys that corresponded to source water surveys (referred to as paired surveys) were measured. The first 50 specimens per sample were measured. The length frequency distribution of bay goby larvae varied among source water sampling locations. The largest numbers of small larvae were collected from sampling stations located in the harbor, as shown in Figure 4-12. Although our sample size of length-frequency varied with the number of larvae among source water sampling stations, the shorter bay goby larvae appear to be missing from both of the Elkhorn Slough sampling sites. Very few bay goby larvae were collected in the upper Elkhorn Slough (Kirby Park). This finding along with a pattern of increasing average larval size and concentration at the Dairies Station suggests that the source of bay goby larvae is somewhere in the direction of the harbor and Monterey Bay. The appearance of larger (possibly older stage) larvae collected in the mid-slough samples (Dairies Station) is consistent with a transport of larvae from a harbor/bay source up the slough. This pattern of shorter to longer larval length from the Monterey Bay to upper slough would point to the Moss Landing Harbor and Monterey Bay as a larval source. The strong pattern of decreasing concentration of bay goby larvae from the harbor-bay to the upper slough also points to the harbor-bay as a primary source of bay goby larvae. This conclusion is consistent with our knowledge of the species' preferred spawning habitat.

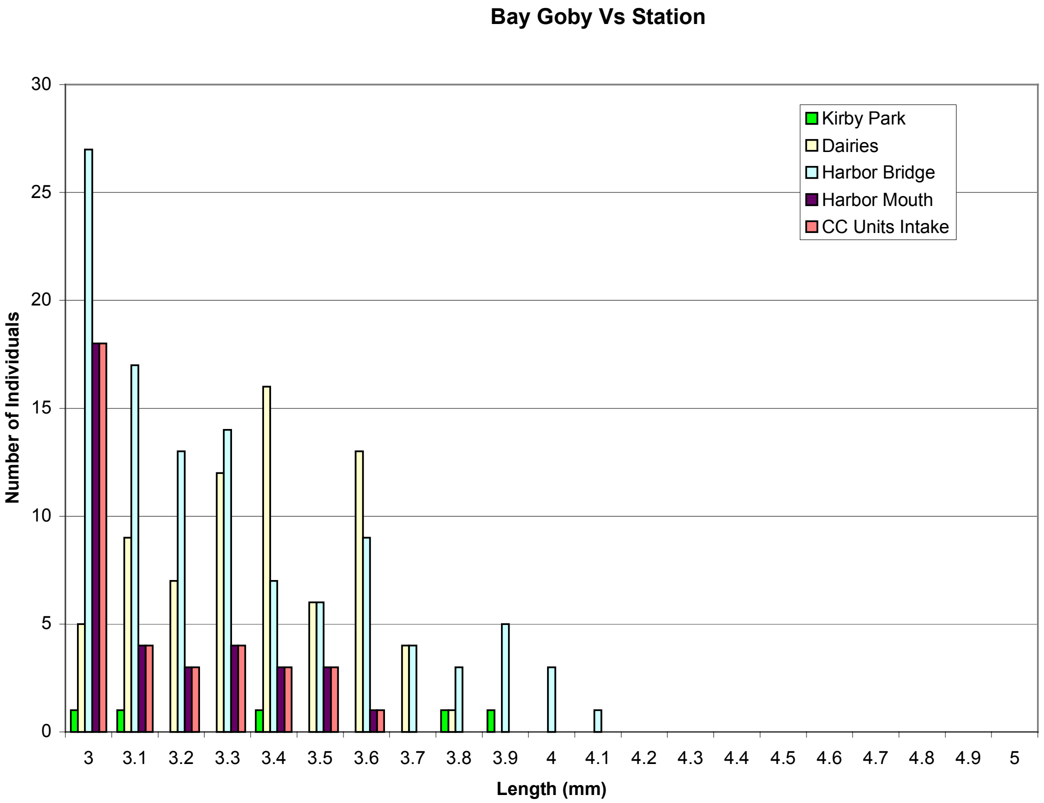


Figure 4-12. Length frequency of all larval bay goby *Lepidogobius lepidus* lengths measured (n=1,111*) by source water and intake sampling locations (June 1999 through January 2000).

*CC Units intake: N = 862; source water survey: N = 249

The length frequency of all bay goby larvae from the paired surveys is plotted in Figure 4-13 along with the length frequency of source water specimens collected at high and low tide stages. The figure shows that more individuals were collected at high tide, particularly in the 3.0 to 3.1 size classes. High tide water quality conditions or currents appear to favor hatching and distribution of bay goby larvae. The length of specimens ranged from 3 to 4.2 mm; the majority of individuals were between 3.3 and 3.6 mm. All of the bay goby lengths measured from both entrainment and source water sub-samples are plotted by survey in the Figure 4-14 scattergram. Inspecting the scattergram for periods of large numbers of smaller individuals followed by periods of fewer and larger individuals to indicate a hatching event, it is possible that a cohort of bay gobies hatched in July and November 1999. However the trends are slight, and the increase in average length between surveys appears to be less than expected based on the growth of individuals in a single cohort. It is more likely that hatching occurred several times during the summer and fall months, and the residual cohort of each hatching pulse blended in with new peaks of hatching larvae.

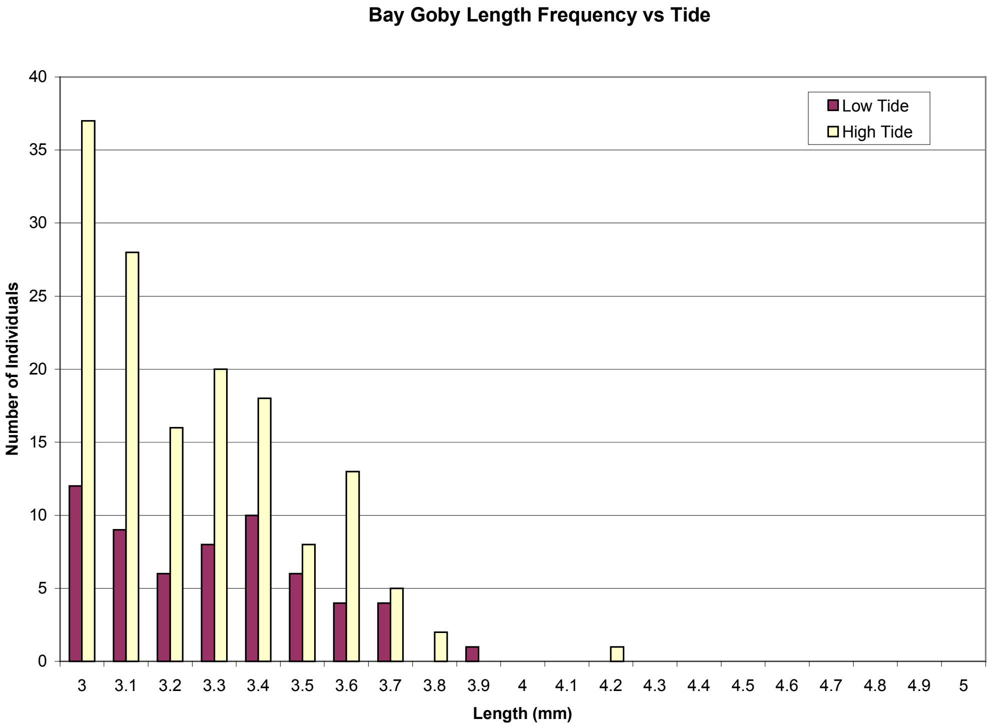


Figure 4-13. Length frequency of all larval bay goby *Lepidogobius lepidus* measured (n=1,111*) by high and low tide stage (June 1999 through January 2000).

*CC Units intake: N = 862; source water survey: N = 249

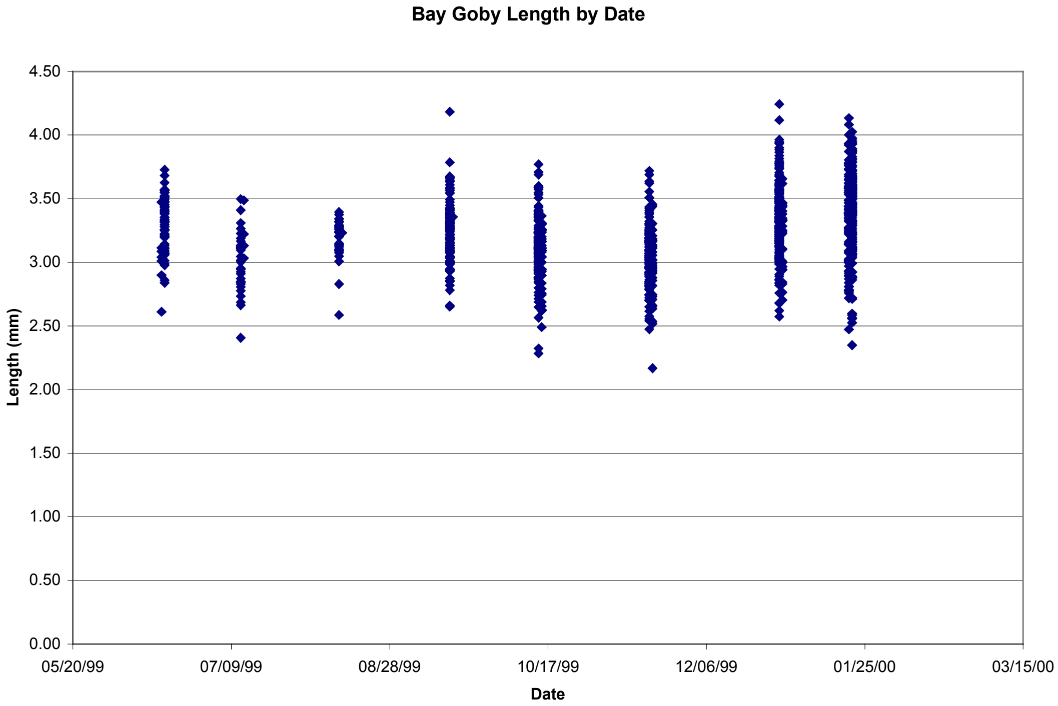


Figure 4-14. Scattergram plot of all larval bay goby *Lepidogobius lepidus* lengths measured (n=1,111*) by source water survey date (June 1999 through January 2000).

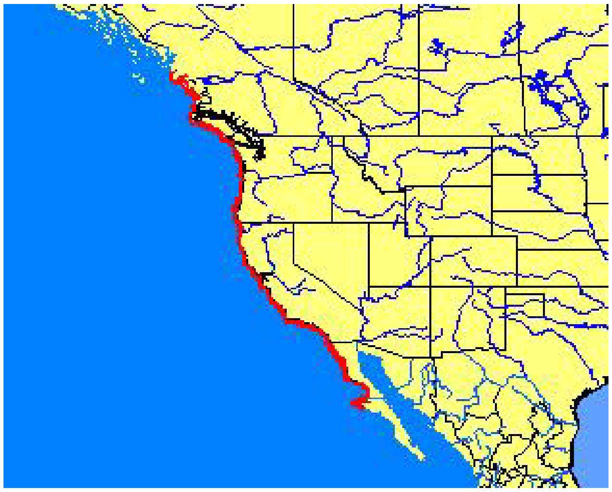
*CC Units intake: N = 862; source water survey: N = 249

Bay goby were not identified in the PG&E (1983) entrainment studies. It is likely that they were collected and that they were included in the general Family Gobiidae data analysis discussed in Section 4.3.

4.5 Blackeye Goby

Photographer: Dan Dugan

Coryphopterus nicholsi



Distribution Map for Blackeye Goby

Range: From Point Rompiente, Baja California to Queen Charlotte Islands, British Columbia.

Life History: Size: to 150 mm (6 in.); Age at maturity: two years, protogynous hermaphrodite; Fecundity: 3,300 to 4,800 eggs; lifespan: five years.

Habitat: Rocky reefs near sand-rock interface.

Fishery: None.

The blackeye goby *Coryphopterus nicholsi* occurs commonly around nearshore reefs from Queen Charlotte Islands, British Columbia to Point Rompiente in Baja California (Miller and Lea, 1972). They are a marine species but will occasionally enter bays and estuaries (Wang, 1986). Blackeye goby typically inhabit benthic substrates near the sand-rock interface. They live in crevices and burrows within small territories that they defend aggressively (Love, 1996). Blackeye goby are known to occur from the intertidal zone down to depths of 137 m (450 ft.) (Love, 1996). The species is reported to be largely diurnal (Love, 1996). Fossil blackeye goby otoliths have been identified from Pliocene deposits in California that are estimated have been formed between 8 and 12 million years ago (Ebert and Turner, 1962). Hart (1973) reported that blackeye goby larvae have the ability to survive exposure to low salinities.

The blackeye goby is an elongate, medium-sized goby that can be distinguished from other members of the family by their large scales, light coloration, and a fleshy ridge that extends dorsally from to just behind the eyes to the insertion of the first dorsal fin (Ebert and Turner, 1962). Blackeye goby reach a maximum size of about 150 mm (6 in.) and have a life span of as much as 5 years (Love, 1996). With the exception of portions of their head, their body is covered with large, cycloid scales (Hart, 1973). Blackeye goby are pale tan to orange-olive in coloration with some brownish and green speckling (Miller and Lea, 1972; Hart, 1973). A small iridescent blue spot is present below each of the large black eyes and the distal margin of their first dorsal fin is tipped with black (Ebert and Turner, 1962; Miller and Lea, 1972; Hart, 1973; Love, 1996). Blackeye goby have a moderate-sized, terminal mouth that is directed forward (Hart, 1973). The joined pelvic fins of males become darker in color during breeding season (Ebert and Turner, 1962; Love, 1996). The species is hermaphroditic (protogynous) so all blackeye goby start life as females (Wiley, 1973; Love, 1996). They become reproductively mature within 2 years and at a total length (TL) of 38 to 51 mm (1.5 to 2 in.) (Love, 1996). Female blackeye goby transform into males at around 64 to 76 mm (TL) (2.5 to 3 in.). Males can be recognized by the presence of a protruding urogenital papilla (Wang, 1986; Love, 1996).

Female blackeye goby are oviparous and based on examinations of ova by Wiley (1973) are able to spawn more than once during a season (Wang, 1986). The spawning season of blackeye gobies extends from February through October (Ebert and Turner, 1962; Wiley, 1973; Love, 1996). Peak spawning activity occurs in the late spring and early summer (Love, 1996). Males prepare a nest by clearing (scraping) an area on the underside of ledges or underneath rocks for egg attachment (Love, 1996). Females deposit between 3,300 and 4,800 elongate/oblong eggs in the nest (Wiley, 1973; Love, 1996). Ebert and Turner (1962) calculated an average nest size of 1,700 eggs. Eggs are demersal and adhesive at the point of attachment (Ebert and Turner, 1962; Wiley, 1973). Nests, formed by a single layer of eggs, are generally circular in shape and average about 100 mm (4 in.) in diameter (Ebert and Turner, 1962). Males guard the nest and tend the eggs until they hatch (Love, 1996). No information was available concerning incubation time. Newly hatched larvae are planktonic and about 3 mm (0.12 in.) in length (Ebert and Turner, 1962). Larvae can be carried great distances by currents and wind action. Juveniles have been found in surface waters far offshore as well as in the stomachs of albacore (Ebert and Turner, 1962). The duration of the planktonic larval phase is approximately 75 days (Steele, 1997). Juveniles begin settling out of the water column at a length (TL) of 21 to 28 mm (0.83 to 1.1 in.) and seek out rocky substrates to commence their demersal life phase (Wang, 1986).

No species-specific larval survivorship estimates were available for blackeye goby. However, Brothers (1975) calculated larval mortality over two-months, post-hatching for three sympatric gobiids (arrow goby, cheekspot goby, and shadow goby) from Mission Bay, California. These estimates were used to approximate bay goby mortality for early life stages as well as post-settlement juvenile and adult stages. Lack of species-specific fecundity data precluded estimation of *FH* for this species, but substituting survivorship from these closely related species for larval, juvenile, and adult stages allowed us to project future losses of equivalent adults.

Blackeye goby consume a variety of small organisms and larval forms. The diet of juveniles includes crustaceans such as copepods and amphipods and their nauplii, as well as mollusk and echinoderm larvae, and bryozoans (Wang, 1986). The diet of adult blackeye goby consists mostly of small crustaceans (copepods and amphipods) and mollusks such as limpets and snails (Love, 1996). During their planktonic stage larval blackeye goby are probably consumed by a variety of species. Juveniles and adults develop predator avoidance behavior but still fall prey to numerous fish and bird species. Diving birds such as pelagic, Brandt's, and double-crested cormorants are among the reported avian predators of blackeye goby (Love, 1996). Blackeye goby are not targeted by commercial or recreational fishermen and are probably rarely, if ever, taken.

4.5.1 Blackeye goby results (3.0 percent)

Blackeye goby comprised 3.0 percent of the total numbers of larval fishes collected in entrainment surveys at the new CC units intake (Figure 4-1). They were collected in all entrainment surveys from March 2, 1999 through December 9, 1999 from in front of the intake of the new CC units (Figure 4-15). They were collected again in low concentrations (below 35/1,000 m^3) in the December 21, December 29, 1999 and January 13, February 3, February 10, and February 24, 2000 surveys. Peak concentration (281/1,000 m^3) occurred on November 11, 1999 and the lowest concentration (1/1,000 m^3) occurred on March 2, 1999. Concentrations were typically below 50/1,000 m^3 for most of the time period sampled.

The diel distributions were plotted for concentrations of blackeye goby collected in front of the new combined-cycle units intake from June 1999 through February 2000 (Figure 4-16). We analyzed only the entrainment surveys that coincided with the source water surveys. They were not collected in the January 2000 entrainment survey that coincided with the source water survey. Blackeye goby were typically collected in highest concentrations during the nighttime between 2200 and 2300 hours PST except in October when the highest concentration occurred after sunset at 1829 PST hours.

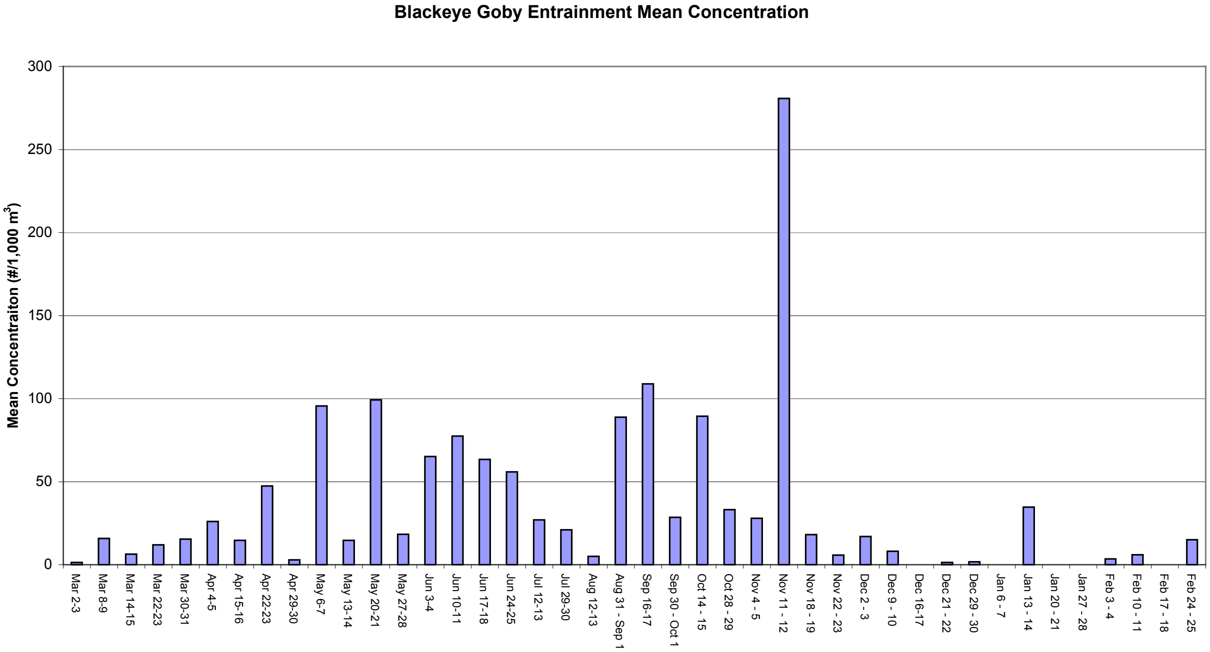
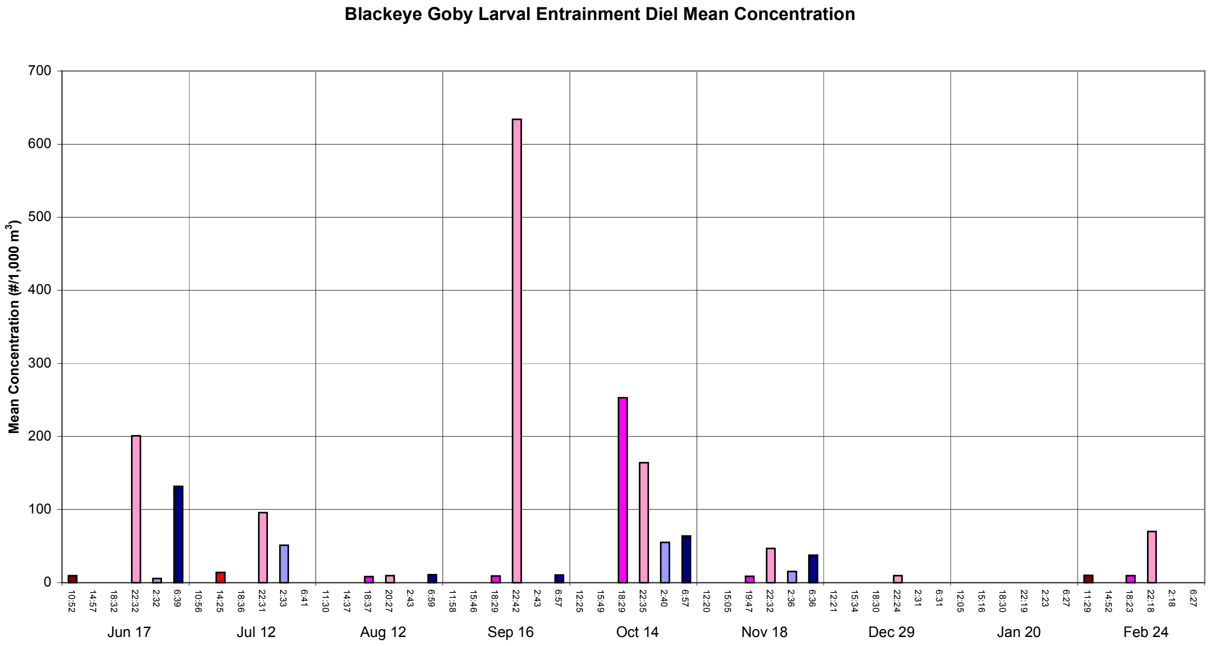


Figure 4-15. Mean survey concentrations (#/1,000 m^3) of larval blackeye goby at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

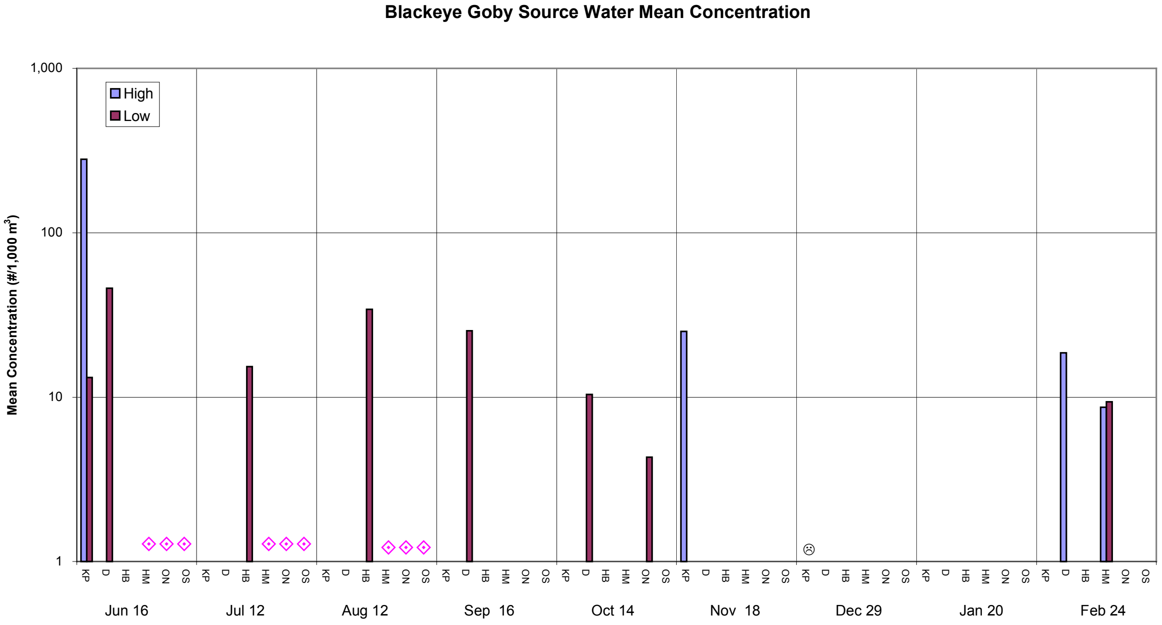


Note: these entrainment surveys were conducted coincidentally with source water surveys.

Figure 4-16. Concentrations (#/1,000 m^3) of larval blackeye goby at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Blackeye goby comprised 1.6 percent of the total fishes collected in the Elkhorn Slough area, 2.9 percent in the Moss Landing Harbor area, and less than 1 percent in the Ocean area from June 1999 through February 2000 (Figure 4-4). Blackeye goby were collected in all months except December 1999 and January 2000 (Figure 4-17). They were only collected at low tides except at Kirby Park in June and November 1999 and the Dairies and Harbor Mouth in February 2000. However, the peak concentration (280/1,000 m^3) occurred at high tide in June at Kirby Park. Blackeye goby were not collected at the Ocean stations except at the Ocean North station during a low tide in October.

Blackeye goby were not identified in the PG&E (1983) entrainment studies. It is likely that they were collected and that they were included in the general Family Gobiidae data analysis discussed in Section 4.3.



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

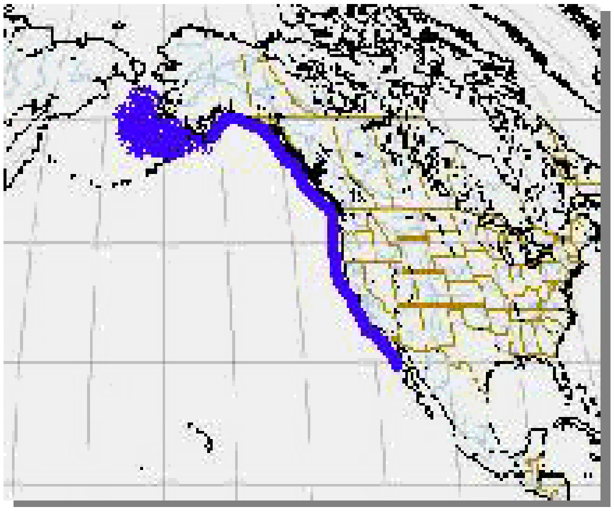
◈ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-17. Source water concentrations (#/1,000 m^3) of larval blackeye goby at six stations near Moss Landing Power Plant: June 1999 through February 2000.

4.6 Pacific Staghorn Sculpin

Leptocottus armatus


Distribution Map for Pacific Staghorn Sculpin

Range: From San Quintin Bay, Baja, California to Chignik, Alaska in the southern Bering Sea.

Life History: Size: commonly less than 254 mm (10 in.); Age at maturity: approximately one year old; Fecundity: 2,000 to 11,000 eggs; Life span: maximum age unknown.

Habitat: Lower reaches of bays and estuaries; shallow muddy and silty substrates; intertidal to depths of 91 m (300 ft).

Fishery: Recreational; common catch from piers, used as bait, primarily in striped bass fishery. Commercial; by-catch in trawl fishery, small bait-fish market.

The Pacific staghorn sculpin belongs to the Family Cottidae, a large group (more than 300 species) of bottom-dwelling fishes. These estuarine fish range from San Quintin Bay in northern Baja California to Chignik, Alaska in the southeastern Bering Sea (Miller and Lea, 1972). They are very abundant in tide pools throughout British Columbia. In the southern half of their range they begin to appear more commonly in freshwater (Moyle, 1976). Pacific staghorn sculpin are abundant in San Francisco, San Pablo, and Tomales bays. They are also common in Moss Landing Harbor and Elkhorn Slough (Jones, 1962).

These slow-moving bottom fish have been reported to be as long as 460 mm (18 in.) in Canadian waters and 310 mm (12 in.) in California. However, Fitch and Lavenberg, (1975) could only document lengths of just less than 254 mm (10 in.). Pacific staghorn sculpin are able to change color to blend in with their surroundings. They are typically grayish green on the dorsal surface, yellowish on the side, and cream colored below. Dark bars appear on the pectoral fins. Staghorn sculpin mature at about one year old (127 mm; 5 in.) and are approximately 5 years old at 254 mm (10 in.). Their maximum age is unknown (Fitch and Lavenberg, 1975).

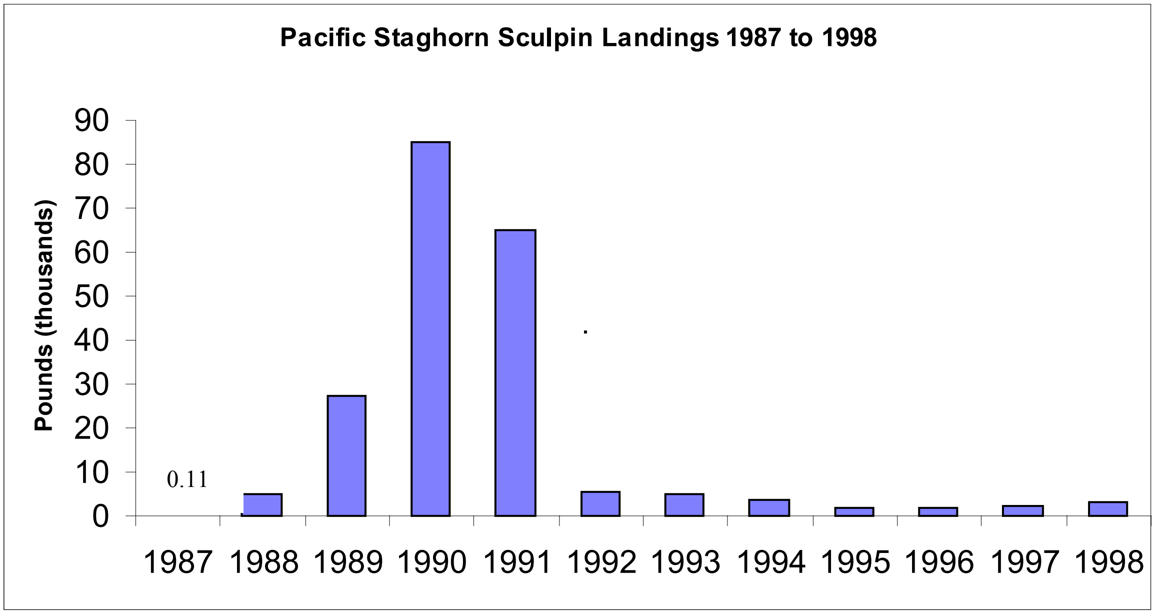
The Pacific staghorn sculpin is classified as a nondependent marine fish, meaning that although commonly found in estuarine environments, it does not require this habitat type to complete its life cycle (Moyle and Cech, 1988). Staghorn sculpin are usually found in shallow subtidal waters, but may be found as deep as 91 m (300 ft). They commonly burrow into sandy mud bottoms of bays and estuaries leaving only their head and eyes exposed. They are occasionally found in the lower reaches of freshwater streams.

Spawning takes place from October through April, with a peak in January and February. Spawning locations tend to be shallow coastal bays, inlets, sounds, and sloughs with optimal salinity measurements between 27 to 28.3 ppt (Jones, 1962). The substrate varies from mud and sand bottoms to more firm rocky areas. The females spawn only once a season, producing between 2,000 to 11,000 spherical eggs, which are deposited in clusters. After spawning, the adults leave the shallow spawning areas for deeper offshore waters (Tasto, 1975). Eggs hatch in about ten days and the larvae (averaging 4.5 mm [0.2 in.] in length) swim to the surface, becoming planktonic (Jones, 1962). It has been suggested (Wang, 1986) that the larvae may remain on the bottom for a short period of time before they ascend to the surface. It takes approximately eight weeks from the time of hatching until larvae metamorphose to juveniles, at a length of 15 to 20 mm (0.6 to 0.8 in.) TL (Matarese et al., 1989). In a Pacific staghorn sculpin population from Anaheim Bay, California, Tasto (1975) reported an estimated growth rate of 13.5 mm (0.53 in.) per month for the months of March and April. Results of a laboratory experiment during those same months exhibited a mean monthly growth increment of 9.1 mm (0.36 in.) (Tasto, 1975).

Juvenile Pacific staghorn sculpin recruit to shallow inshore waters and sloughs. It has been reported that juveniles move up estuaries and into freshwater and remain there for about three months before moving to a more saline environment (Moyle, 1976; Love, 1996). Juveniles probably become demersal after reaching 10 to 15 mm (0.4 to 0.6 in.) in length (Wang, 1986). Their most abundant prey include amphipods, nereid worms, and small anchovy (Jones, 1962).

Adult Pacific staghorn sculpin usually bury themselves while waiting for prey, but will periodically move about in search of crustaceans, polychaete worms, mollusks, other invertebrates, and several kinds of larval, juvenile, and adult fishes. Pacific staghorn sculpin move to the mudflats at high tide to feed, occasionally getting stranded as the tide moves out. A variety of birds search out and feed on the buried adults, as well as on the juveniles who aggregate in the brackish shallows of estuaries. Marine mammals and other fish species commonly feed on the Pacific staghorn sculpin.

Pacific staghorn sculpin are fished for in bays from southern California northward and sold commercially as bait-fish, particularly for the striped bass fishery. Recreational fishermen easily catch Pacific staghorn sculpin from piers and shore, mostly to use as bait. The California state-wide commercial landings for Pacific staghorn sculpin for the last twelve years are shown in Figure 4-18.



Source: CDFG Landing Tables

Figure 4-18. Pacific staghorn sculpin California state-wide landings: 1987 through 1998.

4.6.1 Pacific staghorn sculpin results (2.2 percent)

Pacific staghorn sculpin comprised 2.2 percent of the total numbers of larval fishes collected in entrainment surveys at the new CC units intake (Figure 4-1). They were not collected at the CC units intake entrainment surveys during the first 3 June surveys, July, and September 1999 (Figure 4-19). Pacific staghorn sculpin larvae have been collected in every survey from October 14, 1999 through February 24, 2000. The highest concentration (225/1,000 m^3) occurred on December 16, 1999.

The diel distributions were plotted for concentrations of larval Pacific staghorn sculpin collected in front of the new CC units intake from June 1999 through February 2000 (Figure 4-20). We analyzed only the entrainment surveys that coincided with the source water surveys. Pacific staghorn sculpin larvae were only collected in the October 1999 through February 2000 entrainment surveys that coincided with source water surveys. In November 1999 through January 2000 concentrations were highest at nighttime. In October 1999 they were collected in three cycles (1556 hours, 2235 hours, and 0705 hours PST) in nearly equal concentrations, and in

February 2000 they were collected in nearly equal concentrations at 1129 hours and 2218 hours PST.

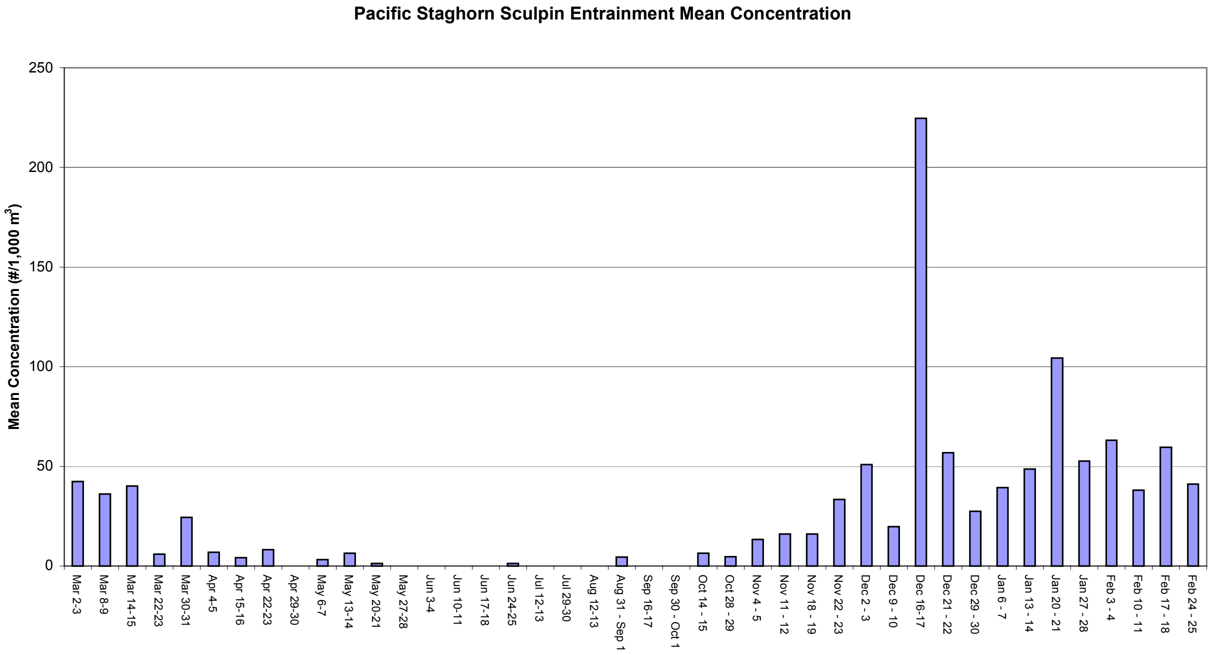
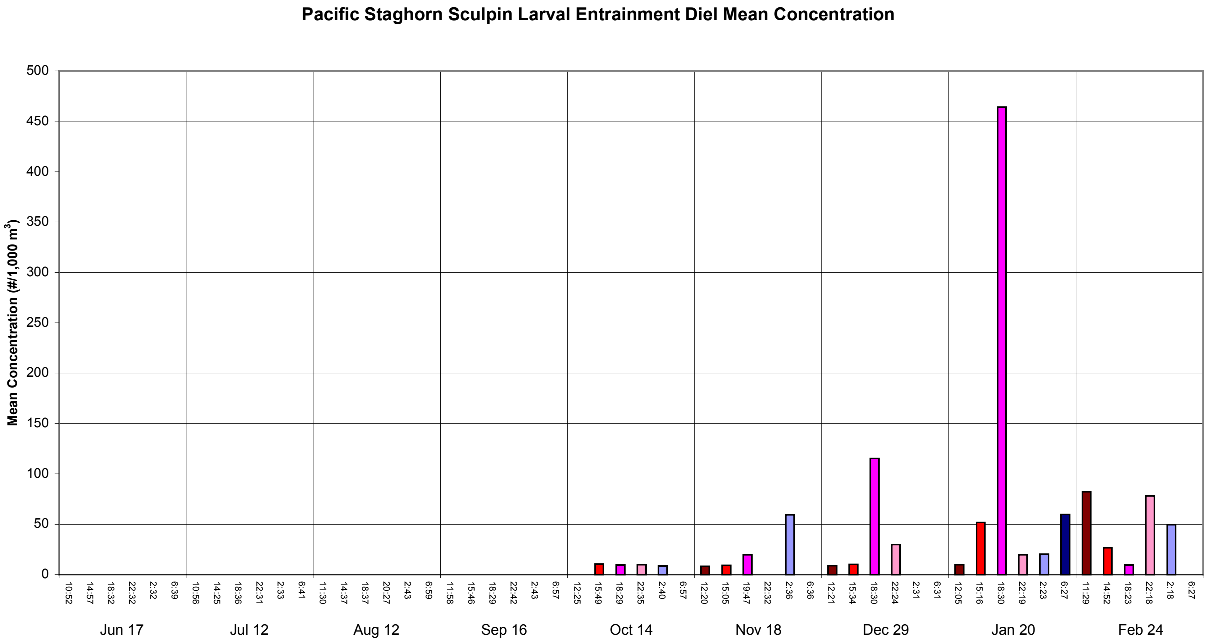


Figure 4-19. Mean survey concentrations (#/1,000 m^3) of larval Pacific staghorn sculpin at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

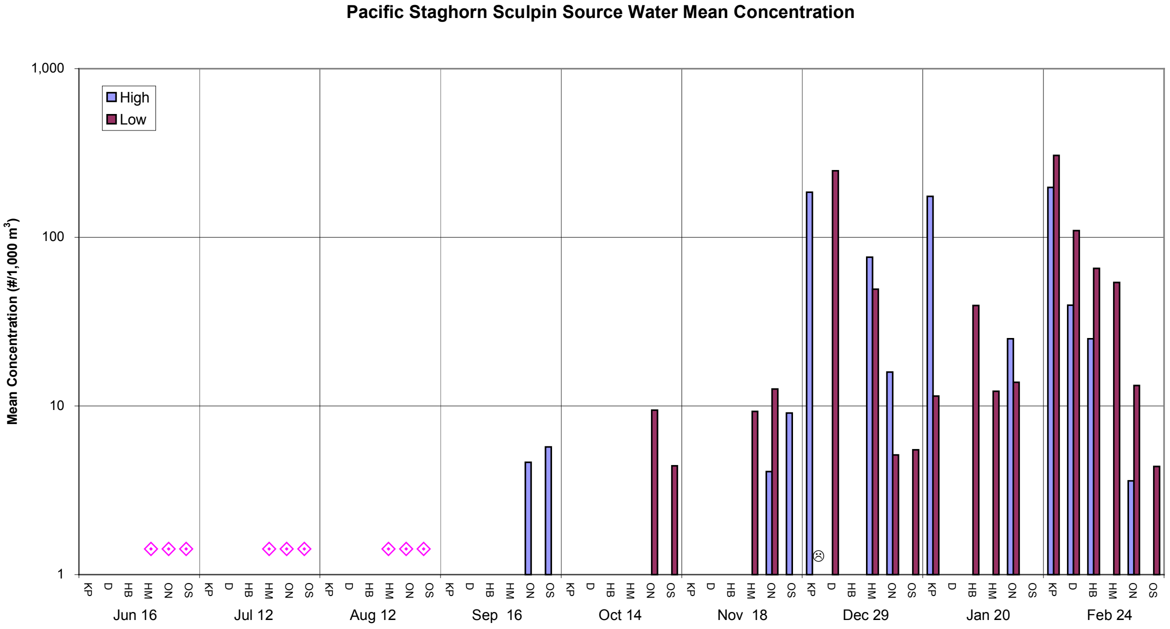


Note: these entrainment surveys were conducted coincidentally with source water surveys.

Figure 4-20. Concentrations (#/1,000 m^3) of larval Pacific staghorn sculpin at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Pacific staghorn sculpin comprised 4.1 percent of the total larval fishes collected in the Elkhorn Slough area, 2.5 percent in the Moss Landing Harbor area, and 2.5 percent in the Ocean area from June 1999 through February 2000 (Figure 4-4). Pacific staghorn sculpin were collected in low concentrations (less than 26/1,000 m^3) in source water surveys from September through November 1999 (Figure 4-21). They were collected at both the Ocean North and Ocean South (except January 2000) stations in each of those six surveys. The highest concentration (306/1,000 m^3) occurred in February 2000 during a low tide at the Kirby Park Station. Another peak in concentration (248/1,000 m^3) occurred at the Dairies Station on a low tide in December 1999.

Pacific staghorn sculpin larvae were entrained at Units 1 through 5 from September 1979 through March 1980 during the first entrainment study (PG&E, 1983). The peak concentration (200/1,000 m^3) occurred at Units 1 through 5 in January 1980 (PG&E, 1983).



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

◇ Stations not included in study design until September.

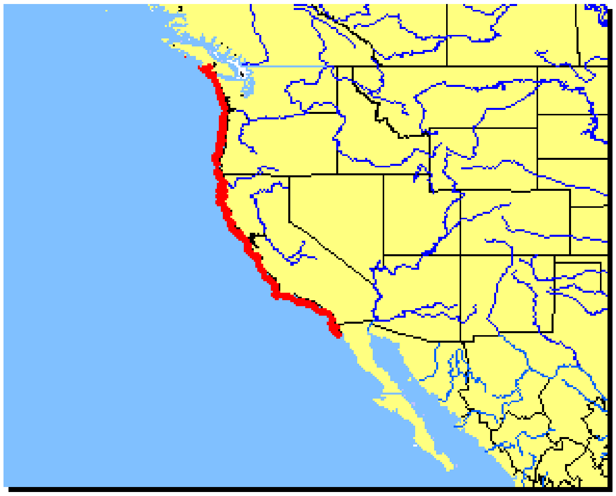
☹ Samples voided due to improper preservation.

Figure 4-21. Source water concentrations (#/1,000 m^3) of larval Pacific staghorn sculpin at six stations near Moss Landing Power Plant: June 1999 through February 2000.

4.7 White Croaker

Source: CDFG

Genyonemus lineatus



Distribution Map for White Croaker

Range: From Todos Santos Bay, Baja California north to Barkley Sound, Vancouver Island, British Columbia.

Life History: Size: up to 380 mm (15 in.) and 0.5 kg (1 lb); Age at maturity: one to four years; Fecundity: spawns 18 to 24 times a season, 800 to 37,000 eggs; Life span: twelve to fifteen years.

Habitat: Near shore and offshore waters to 100 m (328 ft) in depth.

Fishery: Recreational, small commercial market.

The white croaker, also called drum, belongs to the Family Sciaenidae (Order Perciformes) which contains over 210 species. White croaker are found from southern Baja California to Vancouver Island, British Columbia. They are most abundant from southern California northward to about Monterey; they are uncommon north of San Francisco (Love, 1996). They are present in the Sacramento-San Joaquin Estuary, Tomales Bay, and the Moss Landing Harbor/Elkhorn Slough area. In North America, there are about 34 species of croaker, many of them important as sport and commercial fishes (Moyle and Cech, 1988). The white croaker has been given many names; in central California and in most fish markets, “kingfish” is most often used.

White croaker are bottom-dwelling fishes found schooling and feeding along warm, shallow, nearshore coasts. White croaker are usually found in loose schools over sand or mud bottoms of bays and estuaries and in areas less than 30 m (98 ft) deep just outside the surf zone (Streamnet, 1999). They may also, however, inhabit off-shore waters up to 100 m (328 ft) deep (Frey, 1971).

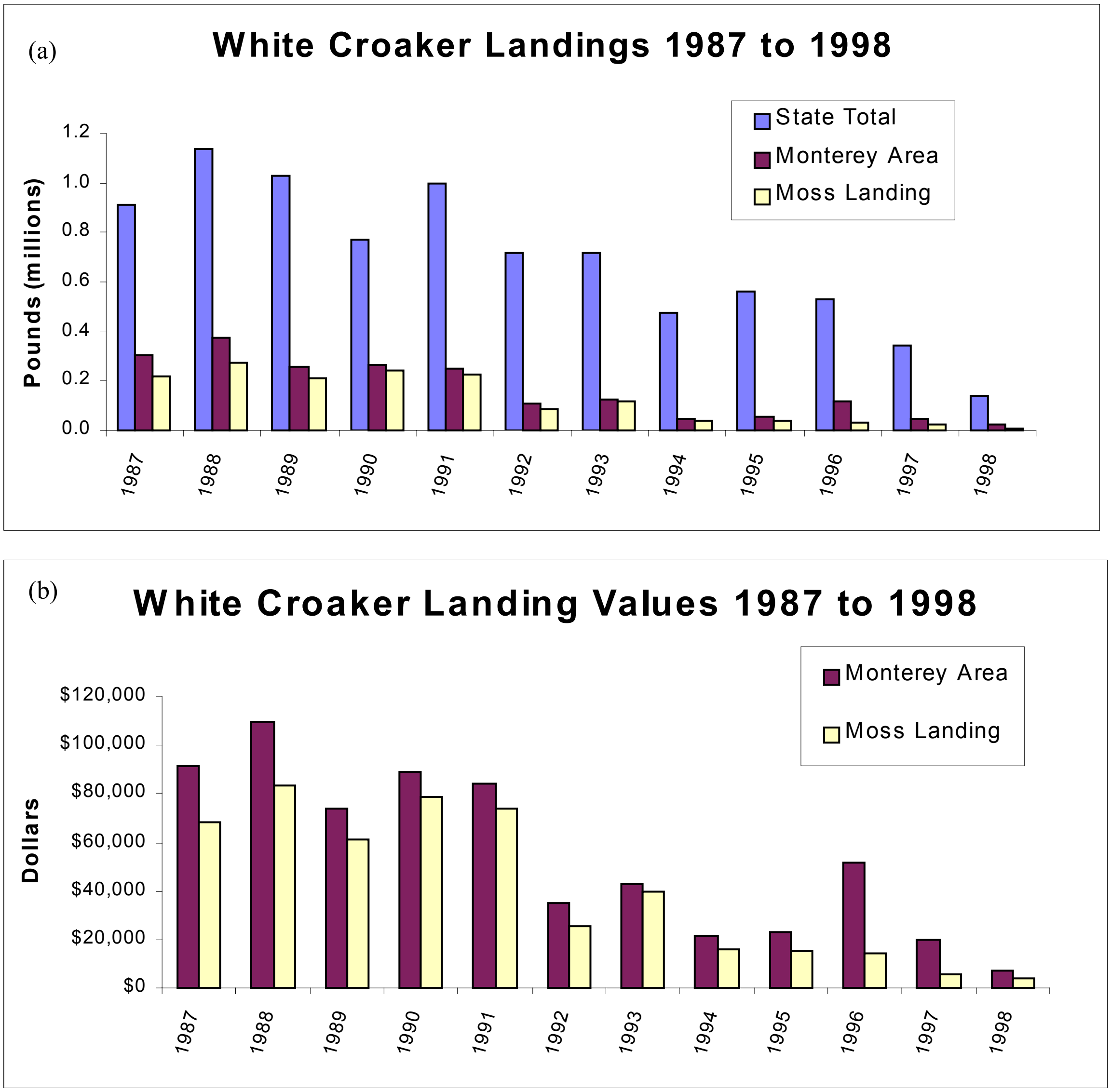
These fish seem to move inshore during summer months and offshore in winter. White croaker, silver in color, can reach 380 mm (15 in.) in length and can weigh over 0.5 kg (1 lb) (Streamnet, 1999). These fish reach maturity in one to four years and may live from twelve to fifteen years (Frey, 1971).

Although some spawning takes place throughout the year, most occurs between November and May (Skogsberg, 1939) with the heaviest concentration during the early spring months. Adults spawn in both near-shore shallow waters and the open waters of bays and estuaries. A large spawning center is located north and south of the Palos Verdes Peninsula, from Redondo Beach to Laguna Beach, and a smaller center is found north of Ventura (Love et al., 1984). Females lay from 800 to 37,000 eggs, and are able to spawn 18 to 24 times a season (Love et al., 1984). The fertilized eggs are pelagic and most drift into the shallow sand and gravel bottom regions of the bays and estuaries.

The spherical eggs hatch in about one week, with the newly hatched larvae averaging about 1.6 mm (0.06 in.) (Watson, 1982). The young larvae are pelagic and post-flexion larvae settle out to the sand and gravel bottom substrate as they develop (Love et al., 1984). There are no species-specific estimates of survivorship in the literature and therefore we assumed a 99 percent larval mortality through settlement. Length frequency analysis of white croaker larvae at the Diablo Canyon Power Plant in yielded mortality rates of approximately 99 percent (Tenera, 2000). Murdoch et al. (1989) estimates a daily larval growth rate of 0.20 mm per day. The shallows of bays and estuaries are used as nursery grounds for the white croaker, but larvae are found in open water as well (Wang, 1986). While a few larvae have been taken as far as 150 miles offshore, most larvae reside within 20 miles of the coast (Love, 1996).

Early juveniles remain in the bays and estuaries; as they mature, the juveniles gradually migrate to deeper ocean waters, usually in the summer and fall (Wang, 1986). Juveniles are approximately 1.3 to 13 cm TL (Emmett et al., 1991). Both juveniles and adults favor cloudy water.

The white croaker, although not of prime importance, has commercial value as bait and as a food fish. Commercial landing information for white croaker in the Monterey and Moss Landing area is shown in Figure 4-22a and b. In addition to man, white croaker are preyed upon by tuna, sea bass, dolphin, halibut, and sea lions. White croaker feed on just about anything, including crabs, shrimps, mollusks, and detritus. Since it is omnivorous and feeds in nearshore waters, the white croaker is susceptible to pollutants accumulating in its tissues. The white croaker fishery has been subject to occasional closures due to health threats to humans.



Source: CDFG Landing Tables

Figure 4-22. (a) White croaker California state-wide, Monterey area, and Moss Landing Harbor landings (1,000,000 lbs) and (b) White croaker California state-wide, Monterey area and Moss Landing Harbor landings values (dollars): 1987 to 1998.

4.7.1 White Croaker Results (2.1 percent)

White croaker comprised 2.1 percent of the total numbers of larval fishes collected in entrainment surveys at the new CC units intake (Figure 4-1). They were collected in four entrainment surveys in March 1999 and the first survey in April 1999 (Figure 4-23). A high concentration (197/1,000 m^3) occurred on March 8, 1999. White croaker larvae were collected on June 24, 1999 in low concentrations (2/1,000 m^3). Beginning in November 1999 they were collected in each weekly survey except on January 21, 2000. The highest peak concentration (226/1,000 m^3) occurred on December 21, 1999.

The diel distributions were plotted for concentrations of larval white croaker collected in front of the new combined-cycle units intake from June 1999 through February 2000 (Figure 4-24). We analyzed only the entrainment surveys that coincided with the source water surveys. During June through October 1999 and during January 2000 no white croaker larvae were collected in entrainment surveys that coincided with source water surveys.

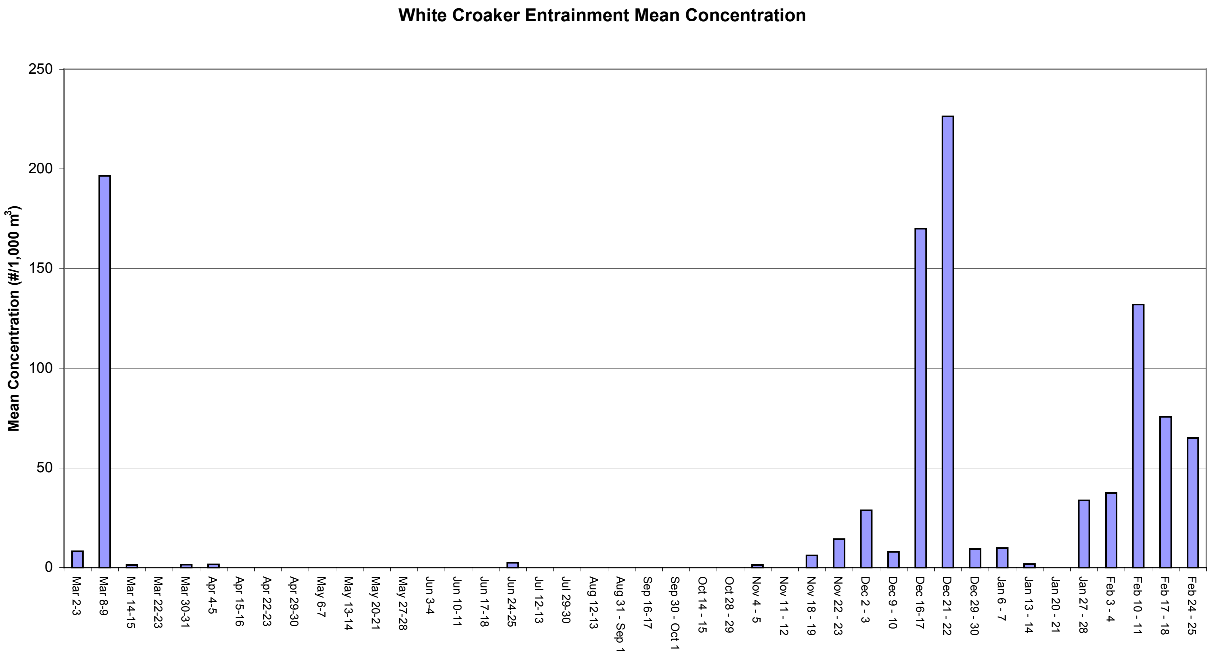
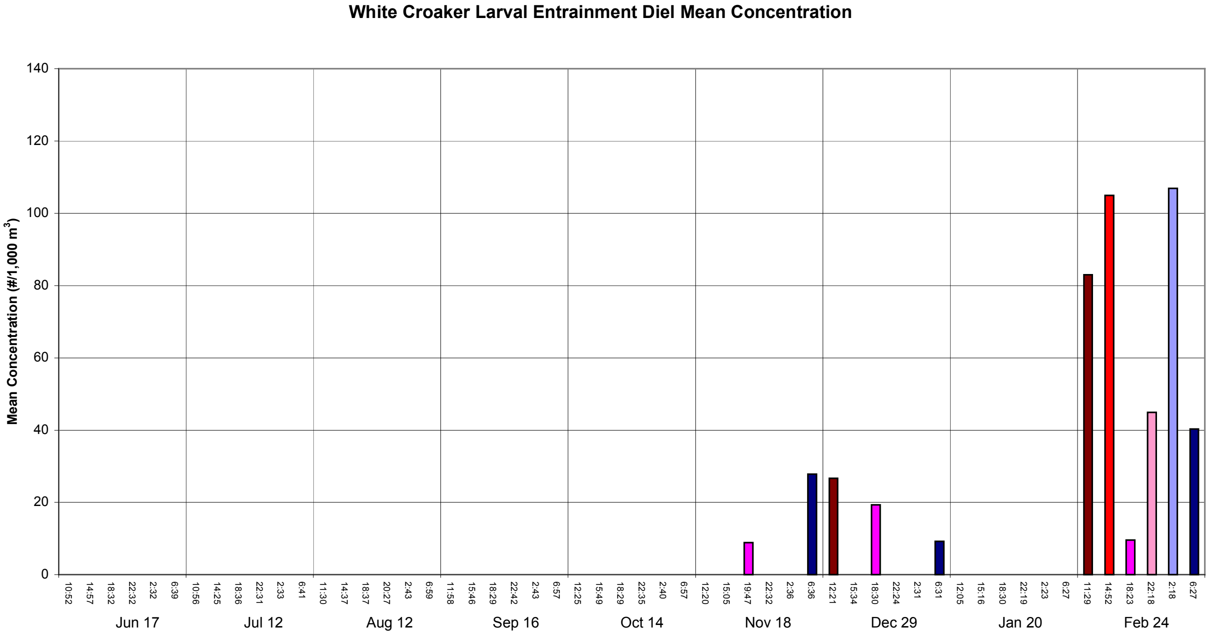


Figure 4-23. Mean survey concentrations (#/1,000 m^3) of larval white croaker at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

In November 1999 larval white croaker were collected in highest concentrations before dawn (0636 PST). In December 1999 and February 2000 larval white croaker were collected in nearly equal peak concentrations during nighttime and daytime.

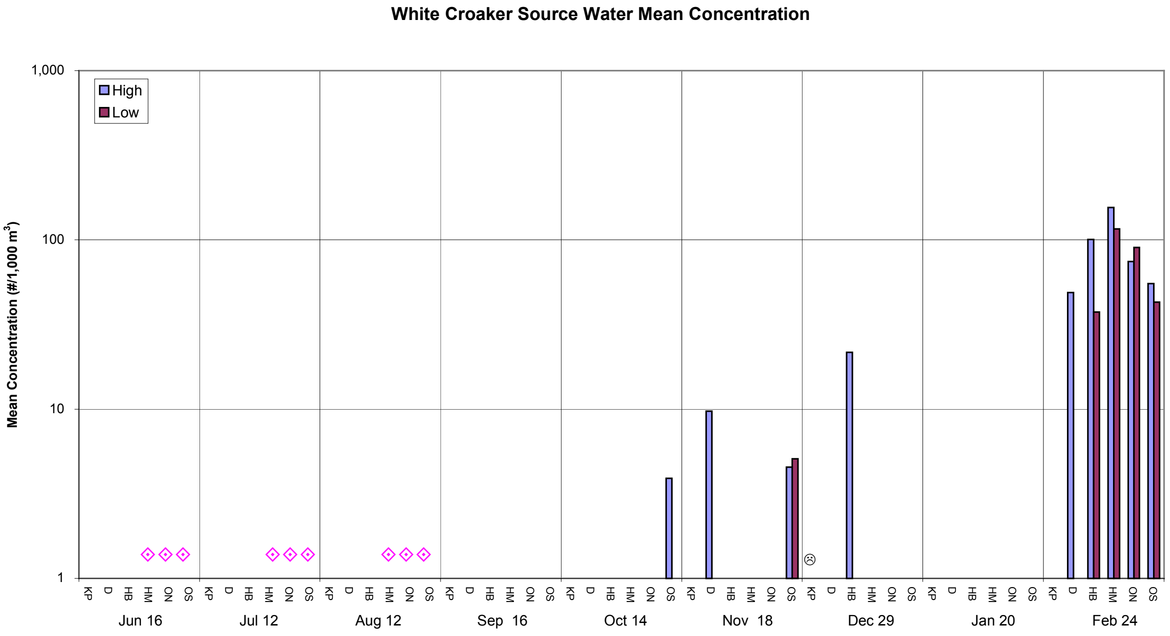


Note: These entrainment surveys were conducted coincidentally with source water surveys.

Figure 4-24. Concentrations (#/1,000 m^3) of larval white croaker at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

White croaker comprised less than 1 percent of the larval fish taxa collected in the Elkhorn Slough area, 0.9 percent in the Moss Landing Harbor area, and 4.4 percent in the Ocean area. White croaker larvae were collected only during the October, November, December 1999, and February 2000 surveys (Figure 4-25). They were collected from the Ocean South Station in October and November, from the Dairies Station in November, and from the Harbor Bridge Station in December. White croaker larvae were not collected at any stations in the January 2000 source water survey. They were collected at all stations except Kirby Park in February 2000. The peak high and low tide concentrations (155/1,000 m^3 and 116/1,000 m^3, respectively) occurred at Kirby Park in February 2000.

White croaker larvae were entrained from August 1979 to March 1980 during the first entrainment study (PG&E, 1983). The peak concentration (400/1,000 m^3) occurred at the Units 1 through 5 intake in November and December 1979 (PG&E, 1983).



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

◇ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-25. Source water concentrations (#/1,000 m^3) of larval white croaker at six stations near Moss Landing Power Plant: June 1999 through February 2000.

4.8 Blenniidae: Combtooth blennies

Combtooth blennies are a prominent group among the fish fauna that inhabits inshore rocky habitats throughout much of the world. They are members of the Family Blenniidae within the Order Blennioidei, which also includes the clinids. Clinids are an extremely variable group of intertidal fishes that includes kelpfish *Gibbonsia* spp. and fringeheads *Neoclinus* spp. The Family Blenniidae, the combtooth blennies, contains around 345 species in 53 genera (Nelson, 1994; Moser, 1996). They derive their common name from the arrangement of closely spaced teeth in their jaws. Four Blenniid species have been reported to occur in the CalCOFI study area, although one, *Ophioblennius steindachneri*, only ranges as far north as Bajia Sebastian Vizcaino in central Baja California (Moser, 1996).

The Family Bleniidae is composed of species that vary widely in general appearance (Moser, 1996). Despite this diversity in appearance the family shares several common external characteristics. Combtooth blennies are all relatively small fishes that typically grow to a total length of less than 200 mm (7.9 in.) (Moser, 1996). Most have blunt heads that are topped with some arrangement of cirri (Moyle and Cech, 1988; Moser, 1996). Their bodies are generally elongate and without scales. Dorsal fins are often continuous and contain more soft rays than spines (Moyle and Cech, 1988). Coloration in the group is quite variable, even among individuals of the same species (Stephens et al., 1970).

Blennies inhabit a variety of hard substrates in the intertidal and shallow subtidal zones of tropical and subtropical marine habitats throughout the world. They may occur to depths of 24 m (80 ft) but are more frequently found in water depths of less than 5 m (15 ft) (Love, 1996). Combtooth blennies are common in rocky tidepools, reefs, breakwaters, and on pier pilings. They are also frequently observed on encrusted buoys and boat hulls. With the exception of the semi-pelagic sabertooth blenny *Aspidontus taeniatus* they tend to be demersal (Moser, 1996). Combtooth blennies are omnivores and eat both algae and a variety of invertebrates, including limpets, urchins, and bryozoa (Love, 1996).

4.8.1 Hypsoblennius Spp.

Combtooth blennies are represented along the California coast by three members of the genus *Hypsoblennius*; the bay blenny *Hypsoblennius gentilis*, rockpool blenny *Hypsoblennius gilberti*, and mussel blenny *Hypsoblennius jenkinsi*. These species co-occur throughout much of their range. The bay blenny *H. gentilis* is found along both coasts of Baja California and up the California coast to as far north as Monterey Bay, although it is absent from the Cape San Lucas area (Miller and Lea, 1972; Stephens et al., 1970). The distribution of the rockpool blenny *H. gilberti* extends from Magdalena Bay, Baja California to Pt. Conception, California (Miller and Lea, 1972; Stephens et al., 1970). The range of the mussel blenny *H. jenkinsi* extends only as far north as Coal Oil Point in Santa Barbara County but occurs south to Puerta Marquis, Mexico (Miller and Lea, 1972; Stephens et al., 1970). Each species appears to have different habitat preferences. The mussel blenny *H. jenkinsi* is only found subtidally and inhabits mussel beds, the burrows of boring clams, or *Serpulorbis* spp. tubes (Stephens et al., 1970). They generally remain within one meter of their chosen refuge (Stephens et al., 1970). Rockpool blenny *H. gilberti* typically inhabit cobble in the intertidal and shallow subtidal zone and may regularly range as far as 15 m (49 ft) within their territories. Bay blenny *H. gentilis* are usually found subtidally but appear to have general habitat requirements and may inhabit a variety of intertidal and subtidal areas (Stephens et al., 1970). Bay blenny are commonly found in mussel *Mytilis* spp. beds and on encrusted floats, buoys, docks, and even fouled boat hulls (Stephens et al., 1970). *H. gentilis* are often found in bays and are tolerant of nearly estuarine conditions (Stephens et al., 1970). They are among the first fish species to colonize new or disturbed marine habitats such as new breakwaters (Stephens et al., 1970; Moyle and Cech, 1988).

There are several morphological differences between the adults of three sympatric *Hypsoblennius* species. The head shape is different, as is the posterior extent of the lateral line (Stephens et al., 1970). In addition, the number of fin rays, coloration, and size may be distinguishing characteristics among adults (Stephens et al., 1970). Bay blenny are the largest of the three *Hypsoblennius* species inhabiting the California coast, reaching a size of 147 mm (5.8 in.) and living for at least 7 years (Stephens et al., 1970; Miller and Lea, 1972). The rockpool blenny attains a size of 140 mm (5.5 in.) and may live for 8 to 10 years (Stephens et al., 1970; Miller and Lea, 1972). Stephens et al. (1970) stated that the rockpool blenny grew faster and attained a larger size than the bay blenny, however, Miller and Lea (1972) lists the bay blenny as growing larger. The smallest are mussel blenny which grow to 112 mm (4.4 in.) and have a life span 3 to 6 years (Stephens et al., 1970; Miller and Lea, 1972). Male and female growth rates are similar. Female rockpool blenny are 64 mm (2.5 in.) TL or more in size before they become reproductively mature (Love, 1996). Some individuals mature within their first year, however it is more common for blenny to become mature in their second (Love, 1996).

The spawning season of the three California *Hypsoblennius* spp. begins in the spring and may extend into September (Stephens et al., 1970). Blennies are oviparous and lay demersal eggs that are attached to the nest substrate by adhesive pads or filaments (Moser, 1996). In *Hypsoblennius* spp., the responsibility for tending the nest resides with the male. Females spawn 3 to 4 times over a period of several weeks (Stephens et al., 1970). Males guard the nest aggressively and will often chase the female away, however, several females may occasionally spawn with a single male (Stephens et al., 1970). The number of eggs a female produces varies proportionately with her size (Stephens et al., 1970). The smaller and shorter-lived *H. jenkinsi* carries relatively more eggs per length than *H. gilberti* (Stephens et al., 1970). A female mussel blenny *H. jenkinsi* may carry 500 eggs in her first year and up to 2,900 eggs by her third year (Stephens et al., 1970). Female rockpool blenny *H. gilberti* may produce from 600 to 3,200 eggs per spawning (Love, 1996). Incubation time is temperature-dependent and eggs typically hatch in 4 to 18 days (Love, 1996).

Larvae of all three species are pelagic and around 2.7 mm (0.11 in.) 2 days after hatching (Stephens et al., 1970). The planktonic phase for *Hypsoblennius* spp. larvae may last for 3 months (Stephens et al., 1970; Love, 1996). Stephens et al. (1970) found that, although all *Hypsoblennius* spp. larvae were the same size at hatching, larvae of the rockpool blenny *H. gilberti* were larger at the time of settlement (18 to 21 mm [0.71 to 0.83 in.]) than either the mussel blenny or bay blenny (12 to 14 mm [0.47 to 0.55 in.]). He assumed that the size difference was the result of more rapid growth rather than a longer larval phase. The accelerated growth rate of the rockpool blenny continued through the first post-larval year as individuals grew to a total length of between 65 and 80 mm (2.6 to 3.1 in.) (Stephens et al., 1970). Mussel and bay blenny of the same age averaged 45 mm (1.8 in.) in total length (Stephens et al., 1970).

Rates of larval mortality were not available for blennids, but Brothers (1975) indicated that 99 percent larval mortality over two months is reasonable for three species of gobies that are ecological analogs in similar habitats. Daily survival was estimated as $(1\text{-}0.99)^{1/60} = 0.926^{d\text{-}1}$. A growth rate of 0.2 mm $^{d\text{-}1}$ was estimated using the difference between transformation length (Moser, 1996; 10 – 22 mm) and hatch length (Moser, 1996; 2.3 – 3.0 mm) and 75 days to settlement (Fitch and Lavenberg, 1975). It was assumed that the age at entrainment was approximately midway to flexion. The growth rate was used to estimate the age of entrainment as 7.8 days, i.e., one half age at flexion (flexion length minus hatch length divided by growth rate). Survival to entrainment was then estimated as $0.926^{7.8} = 0.55$.

Larval survival from entrainment to settlement (75 days) was estimated as $0.926^{75-7.8} = 0.0057$. Adult mortality was estimated from age groupings of three species in Stephens et al. (1970). Exponential instantaneous mortality rates (Z) were calculated from these age groupings using the relationship between log numbers at age $\mathrm{In}(N_t)$ and age t:

$$\mathrm{In}(N_t) = -Zt+b$$

The average of the estimated instantaneous mortality rates (*H. jenkinsi*: Z=0.72; *H. gilberti*: Z=0.57; *H. gentilis*: Z=0.64) was used to estimate annual adult survival of 0.525 yr^{-1}. Using this annual rate, the survival from settlement to age 3.67 year (average age used in fecundity hindcasting) was estimated as 0.11.

Larval blennids are not difficult to distinguish from other larval fishes through a combination of myomere counts, pigmentation patterns and their elongated form (Moser, 1996). The northern range of the bay blenny extends to Monterey Bay while the ranges of adult rockpool and mussel blenny do not extend north of Point Conception, Santa Barbara County (Miller and Lea, 1972). Larval *Hypsoblennius* spp. are not easily distinguished from each other. Because of the long pelagic life phase of the genus, and the corresponding potential for long-range dispersal, it is possible that larval rockpool and mussel blenny could occur in the Moss Landing/Elkhorn Slough area as well as within entrainment samples. For this reason identifications of *Hypsoblennius* spp. larvae were not made past the genus level. All *Hypsoblennius* larvae were combined in the *Hypsoblennius* spp. category. For assessment purposes in Section 6, we assume that the unidentified blennies in our samples are bay blenny.

4.8.2 Blennies *Hypsoblennius* spp. Results (1.9 percent)

Blennies comprised 1.9 percent of the total numbers of larval fishes collected in entrainment surveys at the new CC units intake (Figure 4-1). They were not collected in the entrainment surveys until April 29, 1999 and were present in every survey from May 13 through December 9, 1999 (Figure 4-26). Larval blennies were not collected in the entrainment surveys from December 16, 1999 through February 17, 2000. They were collected in low concentrations (1.6/1,000 m^3) during the February 24, 2000 survey. Peak concentration (272/1,000 m^3) occurred on September 16, 1999. Concentrations were typically below 50/1,000 m^3 for most of the time period sampled.

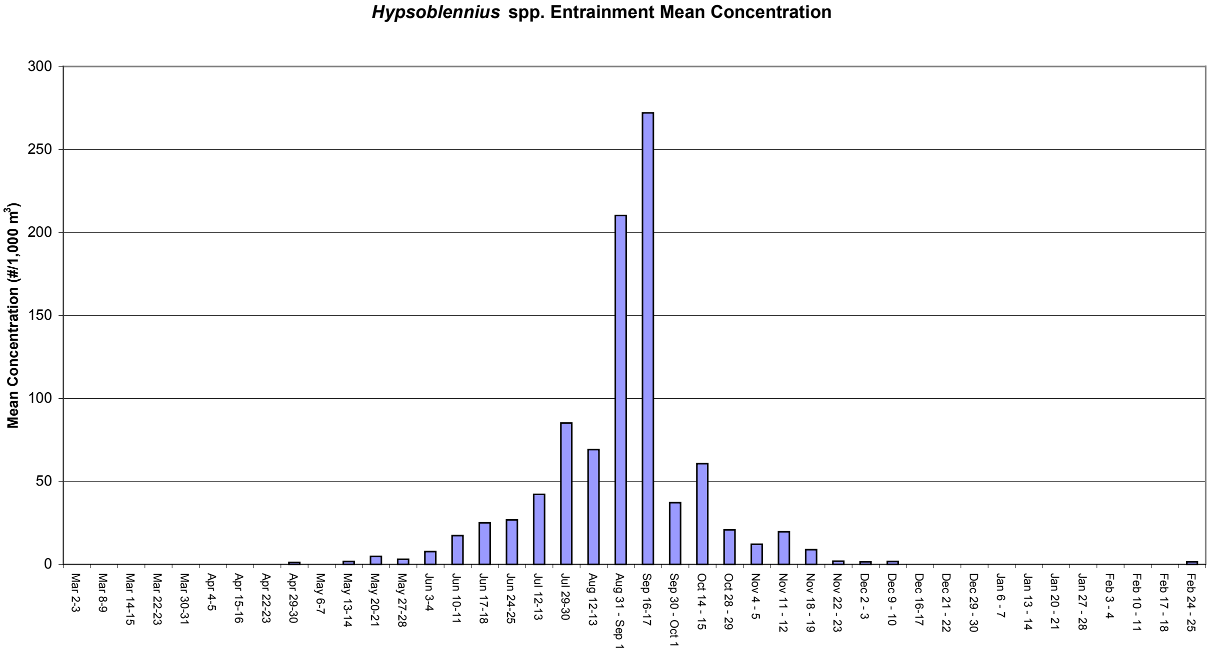
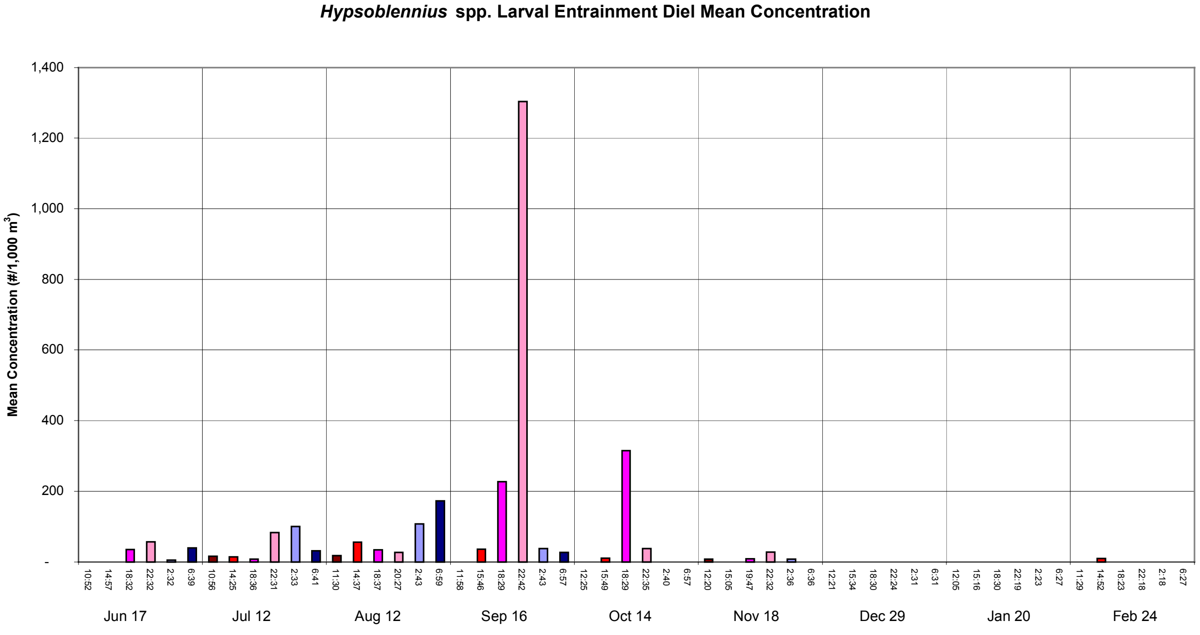


Figure 4-26.. Mean survey concentrations (#/1,000 m^3) of larval *Hypsoblennius* spp. at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

The diel distributions were plotted for concentrations of larval blennies collected in front of the new combined-cycle units intake from June 1999 through February 2000 (Figure 4-27). We analyzed only the entrainment surveys that coincided with the source water surveys; no larval blennies were collected in the December 1999 and January 2000 entrainment surveys. The peak diel concentration of blennies occurred at nighttime between 1830 and 0230 hours PST between June and November 1999, except in August 1999 and February 2000, when the peak concentrations occurred at 0659 and 1452 hours PST, respectively.

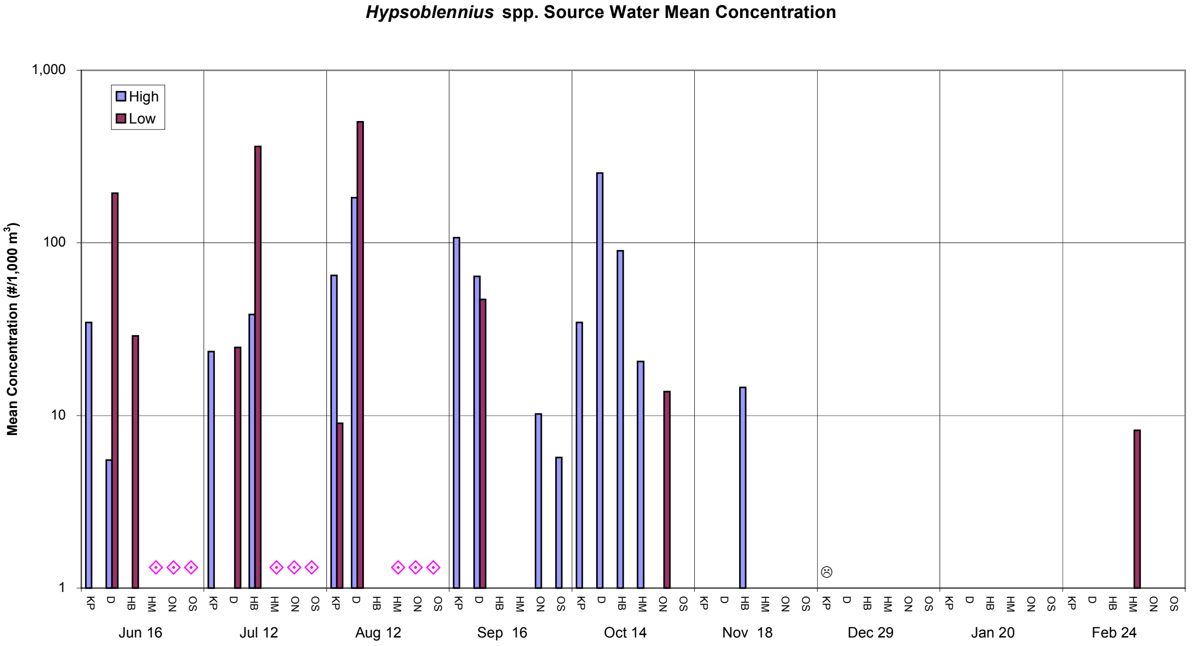
Blennies comprised 6.8 percent of the total larval fishes collected in the Elkhorn Slough area, 5.1 percent in the Moss Landing Harbor area, and 3.0 percent in the Ocean area from June 1999 through February 2000 (Figure 4-4). Larval blennies were collected in all surveys except December 1999 and January 2000 (Figure 4-28). In October 1999, they were collected at all stations except Ocean South. The highest concentrations occurred in June, July, and August during low tide. The highest peak concentration occurred in August (503/1,000 m^3) at the Dairies station.

Larval blennies were not identified in the PG&E (1983) entrainment studies nor have they been collected in other studies of Elkhorn Slough/Moss Landing Harbor (Nybakken et al., 1977; Yoklavich et al., 1992). Since Monterey Bay is the northern most boundary of the *Hypsoblennius* spp. range, it is possible that this is a new species for this area.



Note: These entrainment surveys were conducted coincidentally with source water surveys.

Figure 4-27. Concentrations (#/1,000 m^3) larval *Hypsoblennius* spp. at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

◇ Stations not included in study design until September.

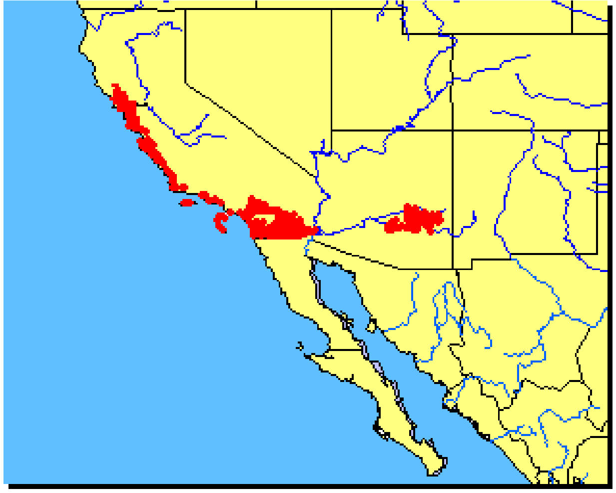
☹ Samples voided due to improper preservation.

Figure 4-28. Source water concentrations (#/1,000 m^3) of larval *Hypsoblennius* spp. at six stations near Moss Landing Power Plant: June 1999 through February 2000.

4.9 Longjaw Mudsucker

Photographer: Drew Talley

Gillichthys mirabilis



Distribution Map for Longjaw Mudsucker

Range: From Bajia Magdalena, Baja California to Tomales Bay, California. In Arizona: the Salt River and the lower Colorado River. Introduced into the Salton Sea, California.

Life History: Size: up to 210 mm (8.25 in.); Age at maturity: one year; Fecundity: spawns two to three times a season, 4,000 to 9,000 eggs; 8,000 to 27,000 eggs (Barlow, 1961); Lifespan: two years.

Habitat: Tidal flats, shallow muddy waters.

Fishery: Commercial and recreational: bait-fish fishery.

The longjaw mudsucker *Gillichthys mirabilis* is a medium to large goby species that commonly inhabits bays, estuaries, tidal sloughs, and salt ponds along the Pacific coast of North America. The native distribution of longjaw mudsuckers extends along the Pacific Coast from Bajia Magdalena, Baja California to Tomales Bay, California (Love, 1996; Wang, 1986). They are most abundant from San Francisco Bay south. An isolated population has been documented in the upper reaches of the Gulf of California and an introduced population has also become well established in the Salton Sea. The latter population is descended from 500 fish that were planted by CDFG during November 1930 (Barlow and De Vlaming, 1972). Longjaw mudsucker have also been reported in Arizona (Roosevelt Lake on the Salt River) and the lower Colorado River where they are commonly used as bait (Fuller, 1999). The occurrence of longjaw mudsucker in these systems is thought to have been derived from bait bucket releases (Fuller, 1999).

Longjaw mudsucker are able to tolerate a wide range of environmental conditions. The species are abundant on tidal flats and in shallow muddy backwaters (Love, 1996). They can live in water with salinities ranging from two and a half times that of seawater to nearly freshwater, and are able to withstand water temperatures as high as 35° C (95° F) (Love, 1996). Their preferred temperature range is between 9° C and 23° C (48° F and 73° F) (De Vlaming, 1971; Love, 1996). Longjaw mudsucker are characterized as having bi-modal breathing capabilities (Moyle and Cech, 1988). In addition to extracting oxygen from the water with their gills, mudsuckers have the ability to absorb oxygen from air taken in (gulped) and held in their large and highly vascularized buccal cavity (Moyle and Cech, 1988; Love, 1996). They also have the ability to undergo limited cutaneous respiration through their fins (Barlow, 1961). They can survive extended periods of time out of the water and have been observed "walking" across tidal flats from one pool of water or burrow to the next (Moyle and Cech, 1988; Todd, 1968). Mudsuckers often retreat into holes and crab burrows when tidal flats are exposed during low tides (Love, 1996). It has been reported that longjaw mudsucker can live out of the water for 6 to 8 days, if they are kept moist (Eschmeyer et al., 1983).

Longjaw mudsucker are olive-brown to dark brown in color with yellowish bellies (Miller and Lea, 1972). Juveniles often have 8 dark bars down the length of their body and a dark blotch on their first dorsal fin (Walker et al., 1961; Love, 1996). Longjaw mudsucker reach a maximum size of about 210 mm (8.25 in.). They are readily distinguished from other similar-looking gobies by their disproportionately long upper jaw, which extends to near the margin of the gill opening. Their pelvic fins fuse to form a disc (Walker et al., 1961).

The life span of longjaw mudsucker is about 2 years (Walker et al., 1961; Love ,1996). They become sexually mature and may spawn in their first year, when they are 25 to 51 mm (1 to 2 in.) long. Longjaw mudsucker are multiple spawners and have been documented spawning 2 to 3 times a year (Walker et al., 1961; Wang, 1986). Spawning activity peaks in the spring but may commence as early as November (in San Francisco and Tomales bays) and extends through July (Barlow and De Vlaming, 1961; Wang, 1986; Love, 1996). The timing of spawning is controlled by environmental cues such as seasonal changes in light and temperature (Moyle and Cech, 1988). Females are oviparous and lay from 4,000 to 9,000 adhesive, club-shaped eggs which are attached to the sides of the burrow with central stalks (Weisel, 1947). Barlow (1961) reported longjaw mudsucker laying between 8,000 and 27,000 eggs. The eggs are guarded by males during their 10 to 12 day incubation period (at 18° C [64° F]) (Weisel, 1947; Wang, 1986). Larvae are pelagic and 3 to 4 mm (0.12 to 0.16 in.) TL at hatching (Wang, 1986). They occur at all levels within the water column (Barlow, 1963; Wang, 1986). Because of heavy pigmentation observed in post-larvae as small as 8 to 12 mm (0.31 to 0.47) TL, the pelagic larval phase of the longjaw mudsucker is thought to be short in comparison to the pelagic phase of sympatric goby larvae (Barlow, 1963). Depending on local hydrographic conditions, larvae can be dispersed over a wide geographic area or remain relatively concentrated near their natal habitats. Larvae settle out at 8 to 12 mm in length (0.31 to 0.47 in.) and begin to develop dense pigmentation (Wang, 1986).

The growth rate of young longjaw mudsucker is rapid but varies seasonally. Fitch and Lavenberg (1975) provided a growth rate for the first year of life of 12.7 cm/year (5 in.; or 0.338 mm/day). A 20 day larval duration was estimated based on a settlement size of 10 mm and hatch size of 3.5 mm (Wang 1986) using the growth rate of 0.338 mm d-1 calculated from 127 mm growth in the first year (Fitch and Lavenberg, 1975). Larval mortality was assumed to be 99 percent over the larval period. Larval lengths ranged from 2.7 to 4.7 mm (mean 3.86 mm) using the center 98 percent of measured lengths. Survival to entrainment was estimated using age 3.4 d, based on growth from the smallest of the 98 percent interval to mean length, as (1-0.99)3.4/20 = 0.455.

Walker et al.(1961) found that the highest growth rates in the Salton Sea population occurred during the hot summer months. By August the modal size of the sampled young-of-the-year (YOY) population had reached a standard length (SL) of 60 to 80 mm (2.4 to 3.2 in.) (Walker et al., 1961). Growth rates had slowed by December with the modal size of yearling goby ranging from 80 to 115 mm SL (3.2 to 4.5 in.) (Walker et al., 1961). Males were observed to grow slightly faster than females (Walker et al., 1961). Longjaw mudsucker are carnivorous and juveniles feed on a variety of invertebrates and occasionally on small fishes. Their diet includes harpacticoids and other copepods, nematodes, and fly larvae of the Family Heliidae (Walker et al., 1961; Wang, 1986). Much of their diet as adults is composed of crustaceans such as crabs and ghost shrimp (Love, 1996). In the Salton Sea, the most important food of adult mudsucker was the pile worm *Neanthes* spp., although they also consumed barnacles, a variety of insect larvae, and an occasional Desert pupfish (Walker et al., 1961). Longjaw mudsucker are preyed upon by a variety of birds and fishes.

Longjaw mudsucker are considered excellent bait and are used in a variety of recreational fisheries. They are considered one of the best baits to use for corvina *Cynoscion xanthulus* in the Salton Sea (Walker et al., 1961). Most mudsuckers used for bait are captured in cylindrical minnow traps. A small commercial bait fishery exists for longjaw mudsucker in the San Francisco Bay Estuary and Delta to supply the needs of striped bass fishermen. Annual landings of longjaw mudsuckers, reported in the CDFG CMASTER database, are generally small. Between 1987 and 1996, state-wide landings ranged from 10 pounds in 1994 to 557 pounds in 1987. No landings were reported in 1990 or 1991. Other sources have reported mean annual catches for the live-bait industry to be around 14,000 pounds.

4.9.1 Longjaw Mudsucker *Gillichthys mirabilis* Results (1.2 percent)

Longjaw mudsucker comprised 1.2 percent of the total numbers of larval fishes collected in entrainment surveys at the new CC units intake (Figure 4-1). They were collected in all entrainment surveys from March 2, 1999 through February 24, 2000 (Figure 4-29). Peak concentration (43/1,000 m^3) occurred on November 4, 1999 and the lowest concentration (1.5/1,000 m^3) occurred on March 8, 1999.

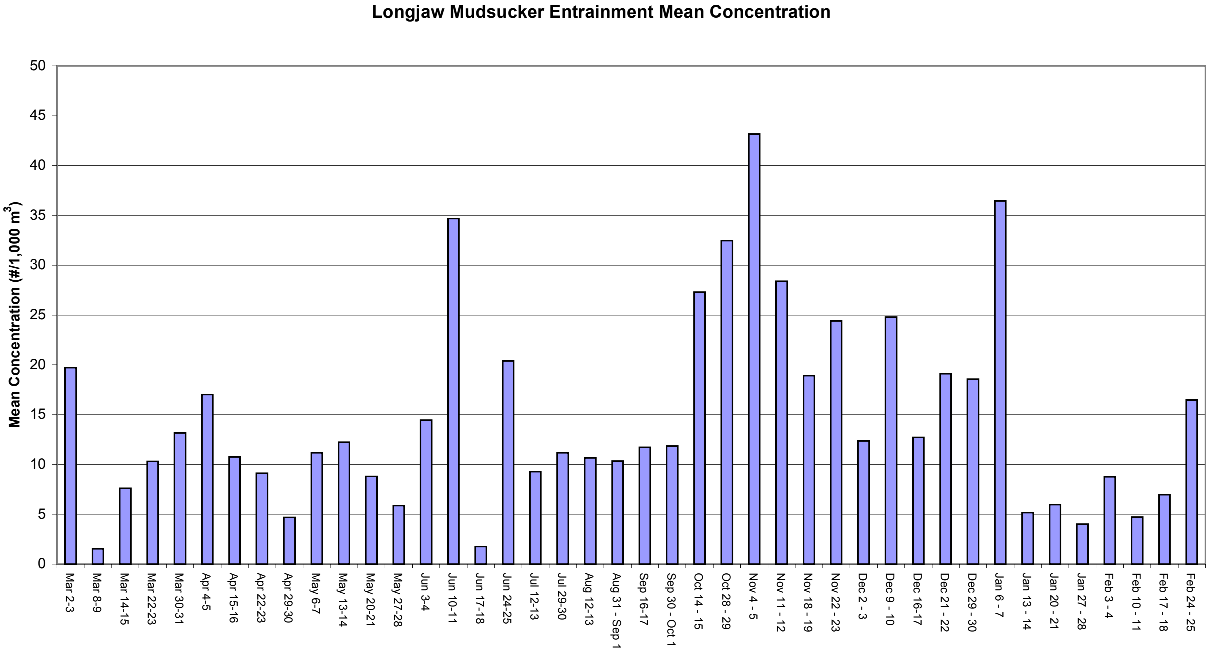
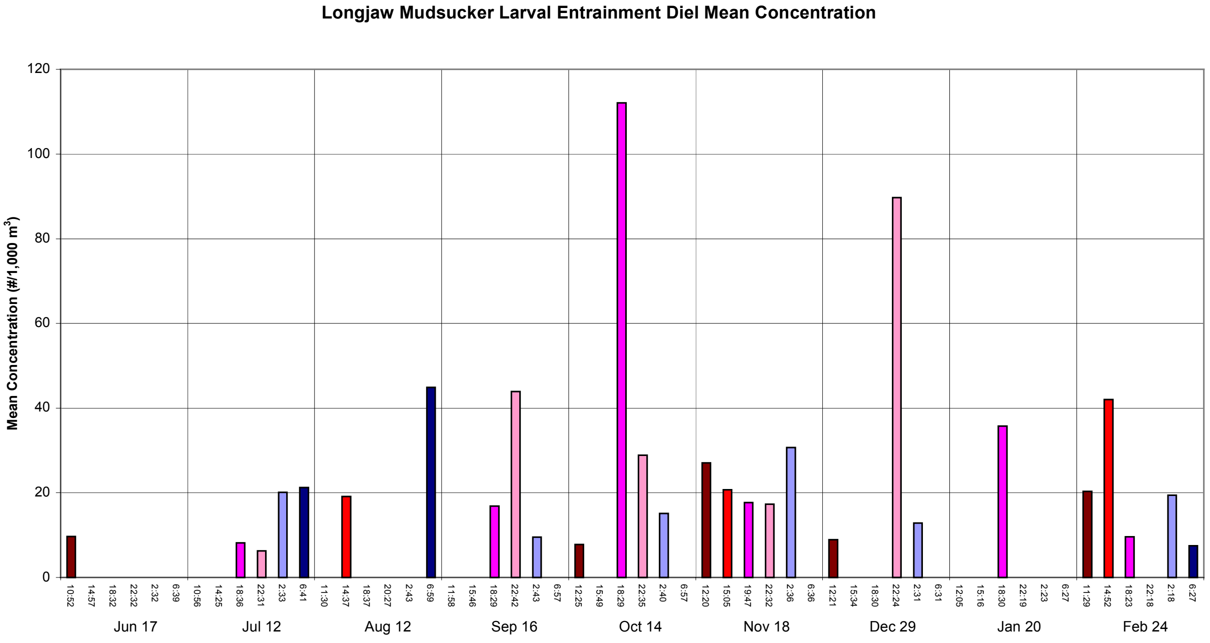


Figure 4-29. Mean survey concentrations (#/1,000 m^3) of larval longjaw mudsucker at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

The diel distributions were plotted for concentrations of larval longjaw mudsucker collected in front of the new combined-cycle units intake from June 1999 through February 2000 (Figure 4-30). We analyzed only the entrainment surveys that coincided with the source water surveys. The diel concentrations of larval longjaw mudsucker varied between night and day. The highest concentrations occurred at night in the September 1999 through January 2000 surveys (Figure 4-30). The highest concentrations occurred in daylight hours during the June and August 1999 and February 2000 surveys. Concentrations were nearly equal between nighttime and daytime during the July 1999 survey.

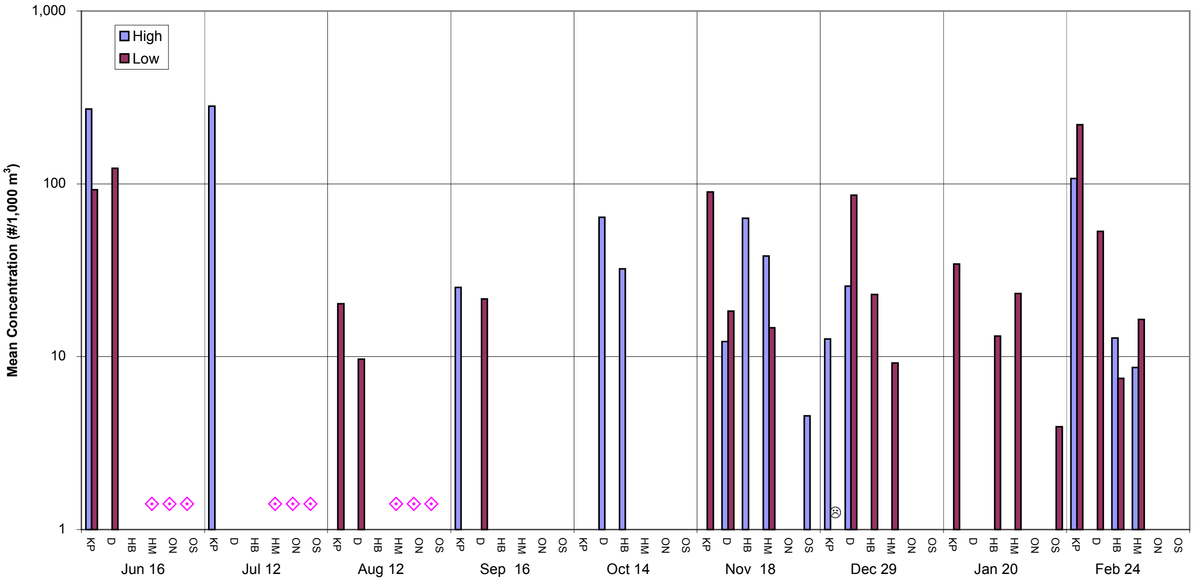


Note: These entrainment surveys were conducted coincidentally with source water surveys.

Figure 4-30. Concentrations (#/1,000 m^3) of larval longjaw mudsucker at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Longjaw mudsucker comprised 5.1 percent of the total larval fishes collected in the Elkhorn Slough area, 1.6 percent in the Moss Landing Harbor area, and less than 1 percent in the Ocean area from June 1999 through February 2000 (Figure 4-4). Longjaw mudsucker were collected in all surveys (Figure 4-31). The peak high tide concentration (272/1,000 m^3) occurred at Kirby Park in July 1999. The peak low tide concentration (219/1,000 m^3) occurred in February 2000 at Kirby Park. Longjaw mudsucker larvae were only collected twice (at Ocean South during high tide in November 1999 and at Ocean South during a low in January 2000) from the two stations located in Monterey Bay.

Longjaw Mudsucker Source Water Mean Concentration



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

◇ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-31. Source water concentrations (#/1,000 m^3) of larval longjaw mudsucker at six stations near Moss Landing Power Plant: June 1999 through February 2000.

All longjaw mudsucker larvae collected from the source water surveys and the new combined-cycle intake surveys that corresponded to source water surveys (referred to as paired surveys) were measured. The length frequency distribution of longjaw mudsucker larvae was similar throughout the source water study area. The generally uniform length of larvae among the various sampling locations, as shown in Figure 4-32, provides little insight into hatching sites based on larval stage. Although the sample size of length-frequency varied with concentrations of larvae among source water sampling locations, the shorter longjaw mudsucker larvae appear to be missing from samples collected both the at the Harbor Bridge and Harbor Mouth stations. This slight pattern of shorter to longer larval length from the upper slough to Monterey Bay would point to the inner slough and marshes as a larval source. A much stronger pattern of decreasing concentration of longjaw mudsucker larvae from upper slough to the Monterey Bay also points to the slough and marshes as a primary source of longjaw mudsucker larvae. This conclusion is consistent with our knowledge of the species' preferred spawning habitat.

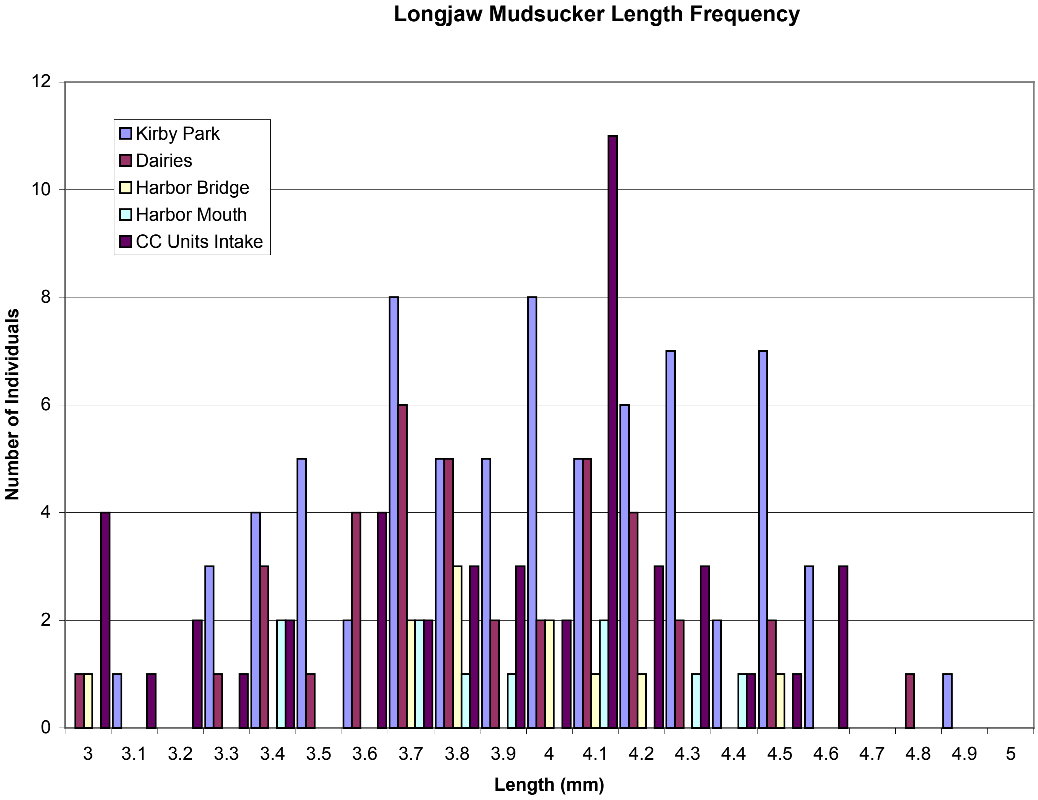


Figure 4-32. Length frequency of all larval longjaw mudsuckers *Gillichthys mirabilis* measured (n=180*) by source water and intake sampling locations (June 1999 through January 2000).

*CC Units intake: N = 47; source water surveys: N = 133

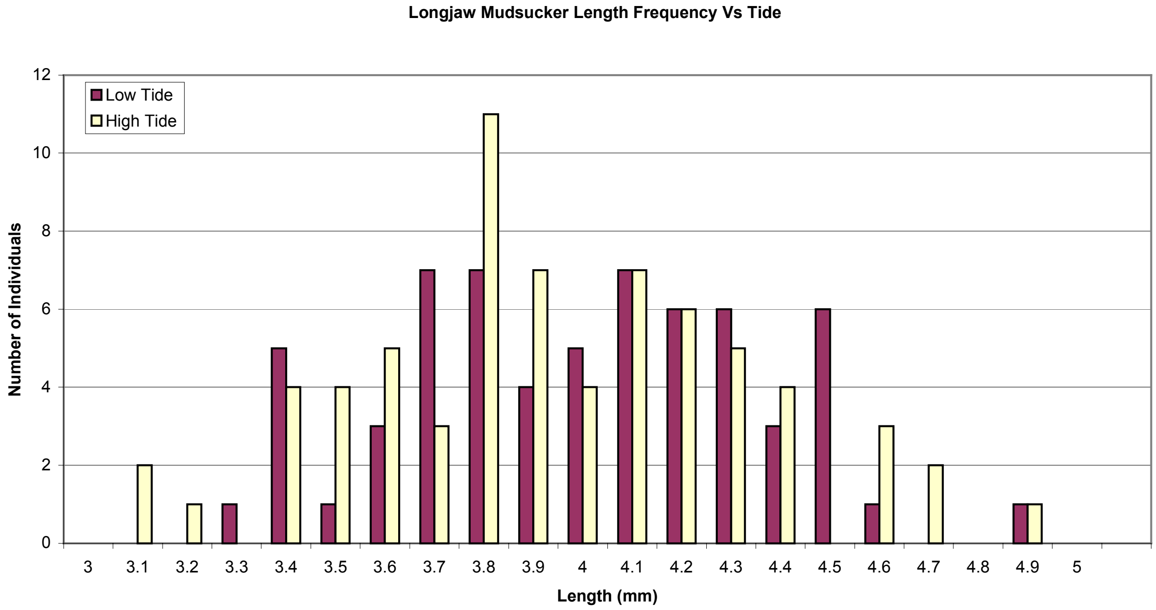


Figure 4-33. Length frequency of all larval longjaw mudsuckers *Gillichthys mirabilis* measured (n=180*) by high and low tide stage (June 1999 through January 2000).

*CC Units intake: N = 47; source water surveys: N = 133

The length frequency of all longjaw mudsucker larvae from paired surveys is shown in Figure 4-33 plotted along with length frequency of source water specimens collected at high and low tide stages. Tidal stage appears to have no relationship to larval stage. Differences in the individual length of specimens were slight ranging from 2.5 to 5.5 mm; the majority of specimens were between 3.4 and 4.5 mm. All of the individual lengths of longjaw mudsucker larvae collected in paired surveys are plotted by survey in the Figure 4-34 scattergram. Looking at Figure 4-34 for periods of large numbers of smaller individuals followed by periods of fewer and larger individuals to indicate a hatching event, it is possible that cohorts of longjaw mudsuckers hatched in July and September 1999. However the patterns are slight, and the increase in length between surveys appears to be less than expected based on growth rate in a single cohort. It is more likely that hatchings occurred throughout the summer and fall months, and the residual fraction of each previous pulse blended into the peaks of newly hatched larvae.

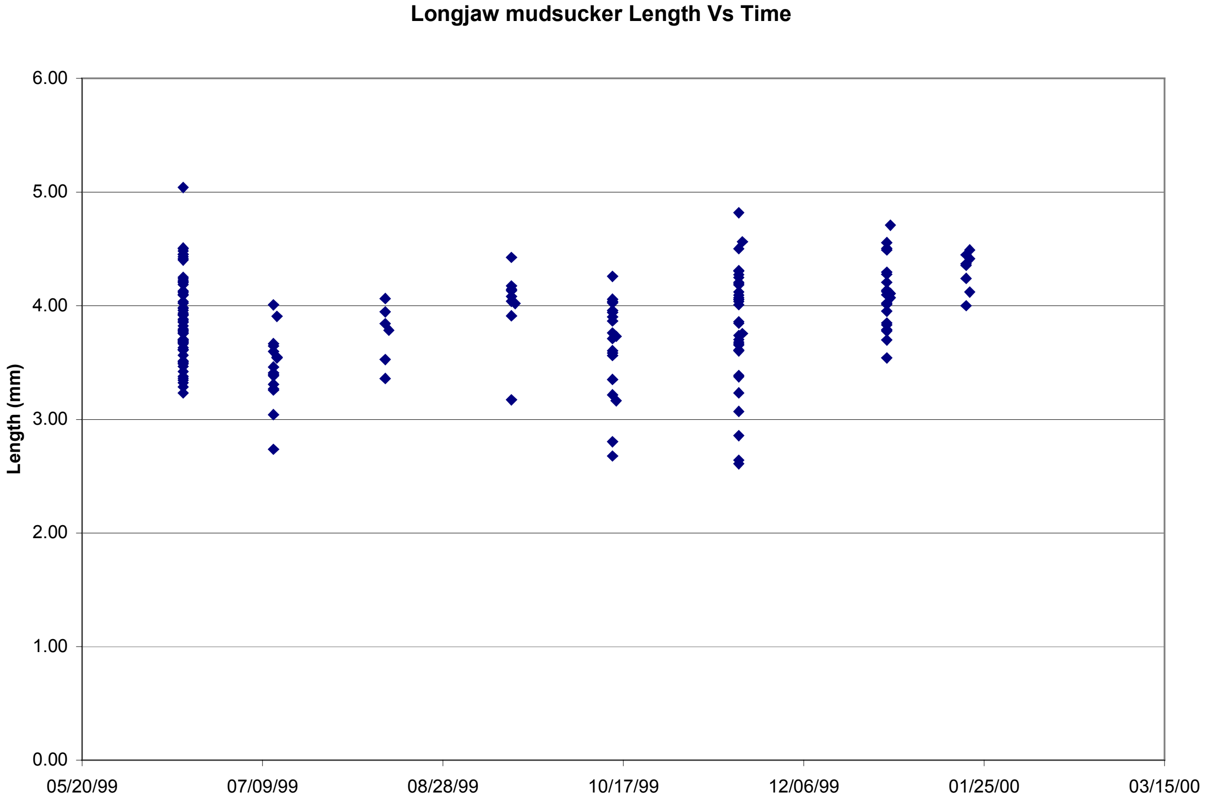


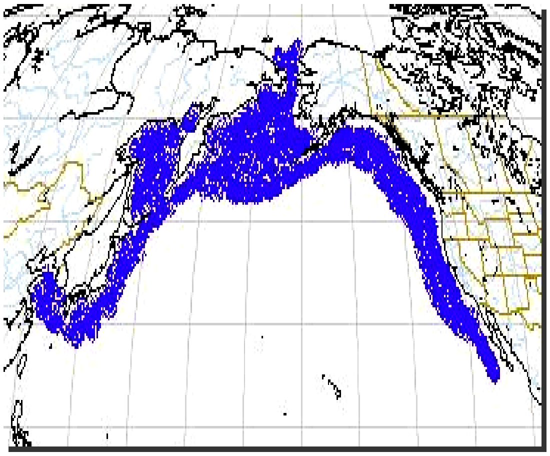
Figure 4-34. Scattergram plot of larval longjaw mudsuckers *Gillichthys mirabilis* lengths measured (n=180*) by source water survey date (June 1999 through January 2000).

*CC Units intake: N = 47; source water surveys: N = 133

Longjaw mudsucker larvae were entrained throughout the study period (November 1978 through March 1980) during the first entrainment study. The peak concentration (150/1,000 m^3) occurred at Units 1 through 5 in September 1979.

4.10 Pacific Herring

Clupea pallasi



Distribution Map for Pacific Herring

Range: From northern Baja California to Toyama Bay, Japan, westward to the Yellow Sea.

Life History: Size: Up to 46 cm (18 in.) and 550 g (1.2 lb); Age at maturity: two to three years old; Fecundity: 4,000 to 130,000 eggs; Life Span: Alaska- to nineteen years, California- to eleven years.

Habitat: A schooling species found near shore to hundreds of miles off shore; spawns in intertidal and sub-tidal zones.

Fishery: Commercial: valuable roe fishery; Recreational: small pier and shore angler fishery.

Pacific herring belong to the Order Clupeiformes which contains some of the world's most numerous and economically important fishes (e.g., herring, sardine, anchovy). The overall distribution of the Pacific herring extends from Baja California to the north Pacific and westward to Japan and the Yellow Sea (Miller and Lea, 1972). In North America, Pacific herring range from Baja California north to arctic Alaska (PSMFC, 1999); they are most abundant off Alaska and British Columbia. In California, most of the populations are found in the San Francisco and Tomales bay areas (Fitch and Lavenberg, 1975). Pacific herring are found from very nearshore areas to hundreds of miles off the coast (Love, 1996).

Pacific herring are small, streamlined marine fishes, measuring up to 46 cm (18 in.) in length and weighing up to 550 g (1.2 lb) (PSMFC, 1999). These slender fish are silvery below and bluish-green to olive above (Love, 1996). Pacific herring stocks living in the waters off of Alaska and Canada tend to grow larger and live longer than the herring off California. In Alaska, herring have been aged to nineteen years old and can measure 38 cm (15 in.) in length. Pacific herring in California may live to eleven years of age and rarely exceed 30.5 cm (12 in.) in length (Fitch and Lavenberg, 1975). California Pacific herring reach maturity at 2 to 3 years of age and at a length of 16.5 to 17.8 cm (6.5 to 7 in.) (Love, 1996).

Pacific herring exhibit important behavioral characteristics such as schooling and diurnal (daily) vertical movement. A school starts to form when a young juvenile approaches the tail of another juvenile; both vibrate rapidly, and begin swimming together. The school increases in size as other fish join, and soon a steady schooling pattern emerges. A school behaves as an individual organism, tightening into a ball when threatened or spreading out when approaching shallow or surface waters. Single schools of herring have been estimated to include many millions of individuals (Svetovidov, 1963). There is a size limit for individuals within a school; the difference between the smallest and largest herring members is approximately 50 percent. The fishes above or below the size limit break away and form new schools. The depths at which herring swim are related to plankton movement, light intensity, temperature, and breeding condition (Svetovidov, 1963). Most herring are believed to stay in deeper water during the day and then make a vertical migration from 300 to 400 m (985 to 1,312 ft) toward the surface at night. These diurnal movements correspond to the movement of plankton and also to temperature, as the fish move from deep colder waters to warmer surface waters.

The spawning activity of Pacific herring is largely influenced by their geographical location. In California, spawning is known to occur in San Diego Bay, San Luis River, Morro Bay, Elkhorn Slough, San Francisco Bay, Tomales Bay, Bodega Bay, Russian River, Noyo River, Shelter Cove, Humboldt Bay, and Crescent City Harbor (Leet et al., 1992). Fish begin entering protected coastal bays, estuaries, and shallow nearshore environments approximately two months prior to spawning (Eldridge, 1977). In the Moss Landing and Elkhorn Slough area, spawning takes place from November through July (Hardwick, 1973). Most spawning occurs during the winter, but a small, noticeable peak occurs from June to July. The southern Pacific herring populations are able to spawn in warmer water temperatures (18° C [64.4° F]) than the Canadian stocks (a maximum observed spawning temperature of 10° C [50° F]) (Alderdice and Velson, 1971).

The majority of spawning habitat is near vegetation in shallow waters ranging from the mean low-tide level to a depth of approximately 4 m (13 ft). The substrate of the spawning grounds tends to be clean, hard, and covered with gravel. Other substrate may include rocks, pilings, and jetties. A soft, muddy bottom may be used if a vegetative cover is available. Males and females spawn simultaneously over a period of 1 to 7 days (Miller and Schmidtke, 1956). The fertilized eggs, broadcast mostly at night, are adhesive and commonly attach to eelgrass, algae, and other intertidal vegetation (Hardwick, 1973). Thousands of females repeatedly deposit their eggs on the vegetation, which can result in egg masses from 10 to 15 layers thick (about 5 cm [2 in.]) (Love, 1996). In large spawning runs, a 9-m (30-foot) wide band of herring eggs may span a distance of 20 miles along the shoreline (Leet et al., 1992). In Elkhorn Slough, Pacific herring are known to broadcast eggs on *Salicornia* spp. (pickleweed), a brackish marsh vegetation (Wang, 1986). Females are capable of spawning only once per season, and after producing between 4,000 and 130,000 eggs, they promptly return to the ocean, leaving the eggs to incubate and hatch. The rate of egg development varies with surrounding water temperature; Pacific herring eggs commonly hatch within 10 to 14 days at 11.8° to 13.5° C (53.2° to 56.3° F) (Wang, 1986). Their salinity tolerance range is 8 to 18 ppt and seems to have no effect on egg development (Fitch and Lavenberg, 1975).

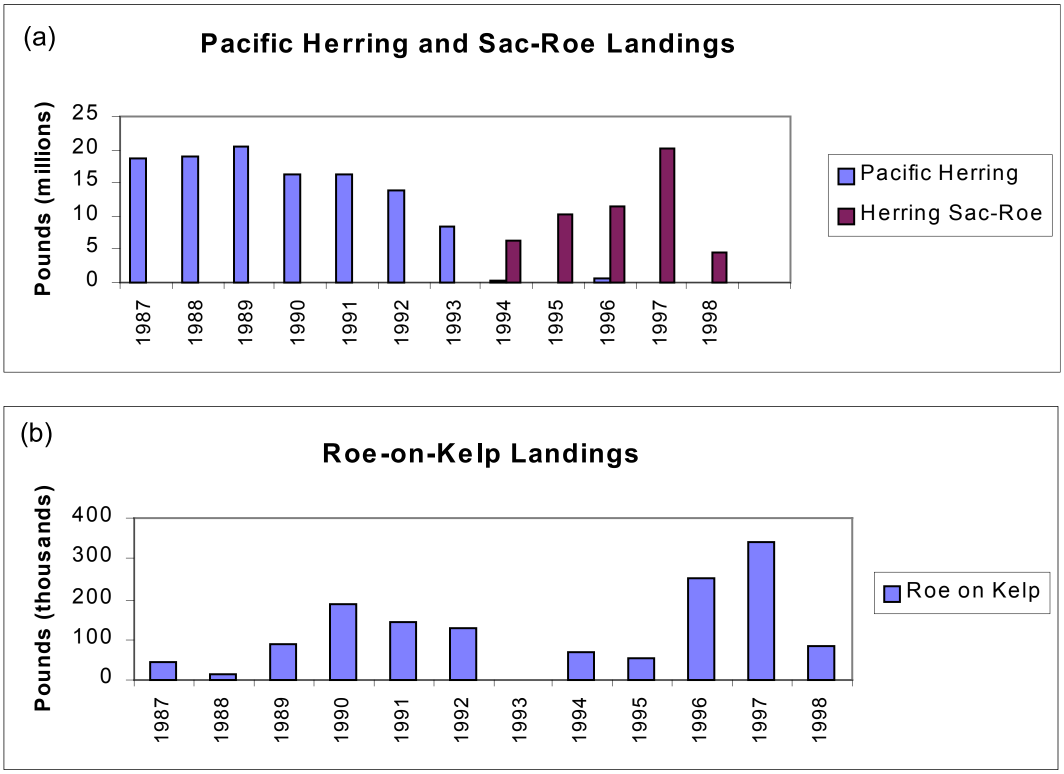
Shortly after hatching, and as the eyes become pigmented, the threadlike larvae move toward the surface waters. They tend to concentrate near the surface and remain for a long time in the area of the spawning grounds. Some larvae, however, have been found several miles out to sea, drifting with the currents (Fitch and Lavenberg, 1975). It takes about 70 days (Hay, 1985) (when larvae are approximately 26 mm TL [1.0 in.]) for the larvae to metamorphose. Metamorphosis is complete by 35 mm TL (1.38 in.) (Stevenson, 1962). Juveniles, depending on geographical region, range from 35 to 150 mm TL (1.38 to 5.9 in.) (Reilly, 1988).

Herring usually reach maturity in 2 to 3 years in California and 3 to 4 years in Washington (Hart, 1973). Pacific herring are pelagic, and while some may remain in the bays and estuaries, most leave and return to the ocean (Eldridge, 1977). At all life stages Pacific herring are plankton feeders, primarily selecting copepods, amphipods, fish larvae, and mollusks. They do not feed during the spawning season, but feed intensively in the summer after spawning.

Pacific herring are a well described species with both age-and stage-specific mortality estimates available from the scientific literature. Egg mortality has been estimated to range from 20 percent (Hourston and Haegele, 1980) to as high as 99 percent (Hardwick, 1973; Leet et al., 1992). Larval mortality can also be derived from the literature and is assumed to be 99 percent through settlement (survivorship = 0.221). Data on larval age and growth (e.g., Stevenson, 1962; Alderdice and Hourston, 1985) are also important for estimating survivorship. Total adult mortality has been estimated as about 50 percent annually ($z = 0.69$) by Hourston and Haegele (1980). Estimates of natural adult mortality (m) are in close agreement from a variety of studies: $m = 0.4 – 0.5$ (Trumble and Humphreys, 1985), $m = 0.39$ (Fried and Wespestad, 1985), $m = 0.36$ (Schweigert and Hourston, 1980), $m = 0.56$ (Gunderson and Dygert, 1988), and $m = 0.31 – 0.71$ (Stocker et al., 1985).

Pacific herring are an important species in the food chain and are fed upon, at all life stages, by many other species including ctenophores (comb jellies), chaetognaths (arrow worms), salmon, lingcod, sharks, seabirds, and marine mammals. Pacific herring are also sought after by man for food, bait, and roe. In addition to predation, they are also subject to being carried out of protective bays and estuaries into areas with little or no food supply. Despite the severe mortality rate, the recruitment of Pacific herring remains high due to their extremely high fecundity, their distribution, and early age of maturity.

The harvest of Pacific herring is a multi-million dollar industry in the United States, with most of the fish coming from Alaska, Washington, and California. The Pacific herring fishing industry is highly regulated north of San Francisco Bay. There are small fisheries in the Monterey and San Francisco area that target Pacific herring for bait and food, but the more valuable fishery involves herring eggs (roe). There is a very lucrative export market for herring roe, especially for kazunoko kombu (roe-on-kelp) which is considered a delicacy in Japan. There are a limited number of permits issued for this fishery in San Francisco Bay. Large amounts of giant kelp, transported from the Channel Islands, are suspended from rafts, which are then anchored in the Pacific herring spawning grounds. At the end of the spawning period, divers collect the kelp and attached eggs, pack it in salt and export the high priced product to Japan. Commercial landing information on Pacific herring, sac-roe, and roe-on-kelp is shown in Figure 4-35a and b.



Source: CDFG Landing Tables.

Figure 4-35. (a) Pacific herring, sac-roe and (b) roe-on-kelp California state-wide landings: 1987 through 1998.

4.10.1 Pacific herring *Clupea pallasi* results *(0.9 percent)*

Pacific herring comprised 0.9 percent of the total numbers of larval fishes collected in entrainment surveys at the new CC units intake (Figure 4-1). They were collected in all entrainment surveys from March 2, 1999 through June 24, 1999 and again in August, October and December 1999 from the new CC units intake (Figure 4-36). They were collected in low concentrations in the August 31 (2/1,000 m^3), October 28 (8/1,000 m^3), and December 2, 1999 (2/1,000 m^3) entrainment surveys. No Pacific herring larvae were collected during the July, September, and November 1999 surveys. They were collected again each week beginning on January 20, 2000 through February 24, 2000. The highest concentration (110/1,000 m^3) occurred on February 3, 2000.

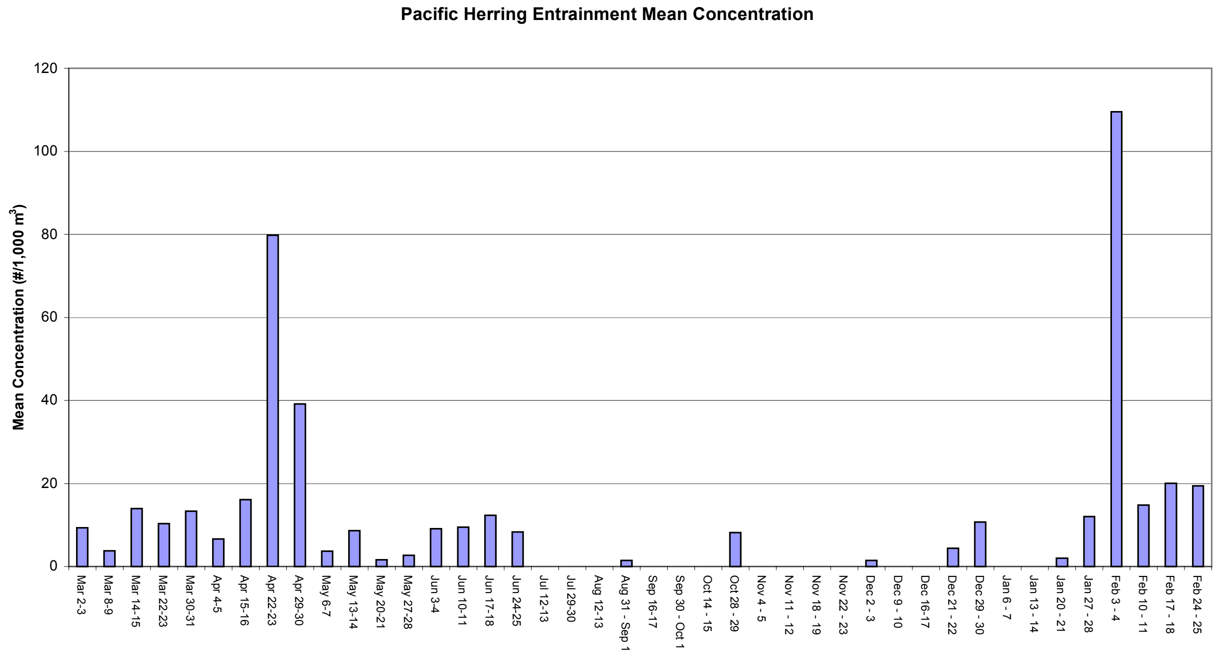
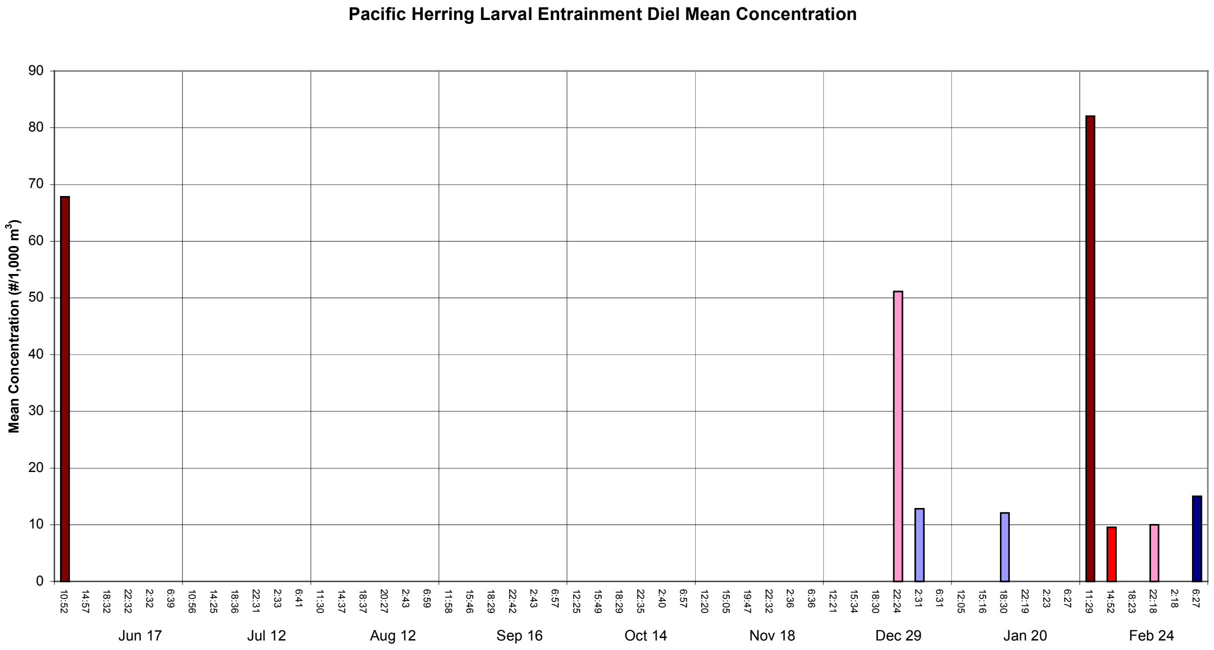


Figure 4-36. Mean survey concentrations (#/1,000 m^3) of larval Pacific herring at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

The diel distributions were plotted for concentrations of Pacific herring larvae collected in front of the new combined-cycle units intake from June 1999 through February 2000 (Figure 4-37). Pacific herring larvae were not collected in the July 1999 through November 1999 entrainment surveys that coincided with the source water surveys. Peak concentrations occurred during the daytime in June 1999 and February 2000. In December 1999 peak concentration occurred at 2224 hours PST, and in January 2000 they were only collected at 1830 hours PST.

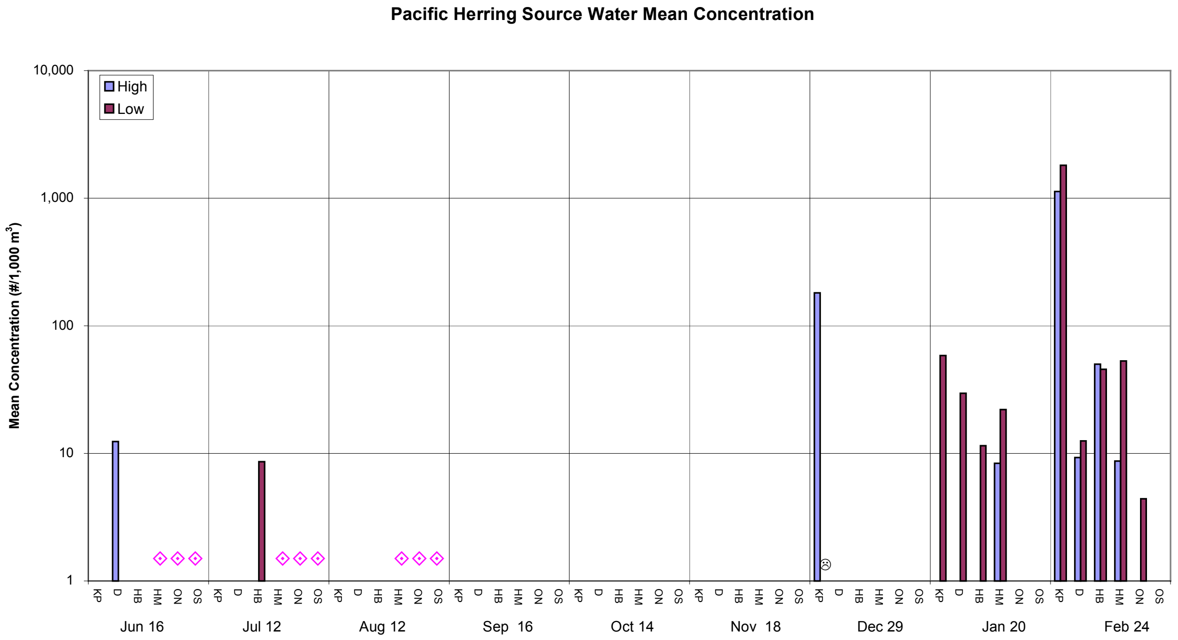


Note: these entrainment surveys were conducted coincidentally with source water surveys.

Figure 4-37. Concentrations (#/1,000 m^3) of larval Pacific herring at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Pacific herring larvae comprised 10.9 percent of the larval fish taxa collected in the Elkhorn Slough area, less than 1 percent in both the Moss Landing Harbor and Ocean areas. They were not collected at any source water stations in August, September, October, and November 1999 (Figure 4-38). The peak concentration occurred at Kirby Park during low tide in February 2000 (1,815/1,000 m^3). The peak high tide concentration (1,127/1,000 m^3) also occurred at Kirby Park in February 2000.

Entrainment data showed two spawning periods for Pacific herring during the first entrainment study (PG&E, 1983). Pacific herring larvae were entrained between May 1979 and early August 1979 and again from December 1979 through March 1980 (Figure 4-38). The peak concentration (460/1,000 m^3) occurred at Units 1 through 5 in January 1980 (PG&E, 1983). Peak concentrations from the previous entrainment study (PG&E, 1983) occurred at Units 1 through 5 in January 1980.



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

⟐ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-38. Source water concentrations (#/1,000 m^3) of larval Pacific herring at six stations near Moss Landing Power Plant: June 1999 through February 2000.

4.11 Rock Crabs Family Cancridae

Rock crab are decapod crustacea belonging to the infraorder Brachyura and Family Cancridae. Four commercially important crab species, the dungeness crab *Cancer magister*, the Pacific or brown rock crab *Cancer antennarius*, the red rock crab *Cancer productus*, and the yellow rock crab *Cancer anthonyi* inhabit overlapping ranges along the Pacific Coast of North America. The four species occur sympatrically. However, the relative abundance of each differs geographically (Carroll and Winn, 1989; Jensen, 1995). Along the coast of California red rock crab and dungeness crab are more common in the north, yellow rock crab in the south, and the brown rock crab is generally more abundant in the central regions of the state (Carroll and Winn, 1989; Parker, 1992). Rock crab inhabit a variety of substrata including rock, gravel, sand, sandy-silt, and mud (Winn, 1985; Carroll and Winn, 1989). All four species occur in the low intertidal zone. However, the maximum depth range reported for each differs (Morris et al., 1980; Carroll and Winn, 1989; Jensen, 1995). The first stage zoeae of slender rock crab *Cancer gracilis* were collected in Elkhorn Slough and in offshore waters of Monterey Bay which suggested that adult females used the area for spawning (Hsueh, 1991).

The carapaces of rock crab are broad and generally oval in shape, however the proportions and dorsolateral shape varies species to species. The margin of the anterior half of the carapace of each species is lined with an equal number of teeth (anterolateral teeth) on each side of the body. The characteristics (number, relative size, or appearance) of these teeth are different in each species (Schmitt, 1921; Carroll and Winn, 1989). The dorsal and ventral coloration of the exoskeleton also varies between the species (Carroll and Winn, 1989). All three species have dark-tipped claws. Adult rock crabs are sexually dimorphic with males attaining a larger size and growing larger, more robust chelae (claws). The shape of the abdominal flap of a rock crab, as with all brachyura, is the most definitive external sexual characteristic. In males the abdominal flaps are slender and narrow to a point while those of females are broad and rounded.

Details of the reproductive behavior of rock crabs have not been well documented in literature, but are thought to follow a pattern similar to other cancrid crabs. Mating only occurs immediately after a female ecdysis (molt), when she is in a soft-shelled condition (Carroll and Winn, 1989). A male rock crab, stimulated by pheromones released from the female before she molts, will locate and “embrace” the female in a face-to-face position (Carroll and Winn, 1989; Jensen, 1995). This embrace continues through molting, insemination, and the initial hardening of her exoskeleton (Carroll and Winn, 1989). During the insemination phase, the male inserts his gonopod (paired pleopods) into the spermatotheca of the female and deposits a spermatophore (Carroll and Winn, 1989; Jensen, 1995). The sperm contained in the spermatophore can be viable for more than a year and may be used by the female for multiple spawnings (Carroll and Winn, 1989). Following mating the spermatophore hardens to form a plug that closes off the spermatotheca and is thought to prevent further mating by the female (Carroll and Winn, 1989; Jensen, 1995). Fertilization occurs internally as the eggs are being extruded (Carroll and Winn, 1989). Egg extrusion occurs about 11 weeks after mating and the female carries the egg mass under her abdominal flap (attached to setae on the endopodites of the pleopods) until the eggs hatch (Carroll and Winn, 1989). Ovigerous, or "berried" females are found throughout the year however their season of peak abundance varies somewhat from species to species (Toole, 1985; Winn, 1985; Reilly, 1987; Carroll and Winn, 1989). Variations in the size of a female's egg mass occur between individuals and species (Carroll and Winn, 1989).

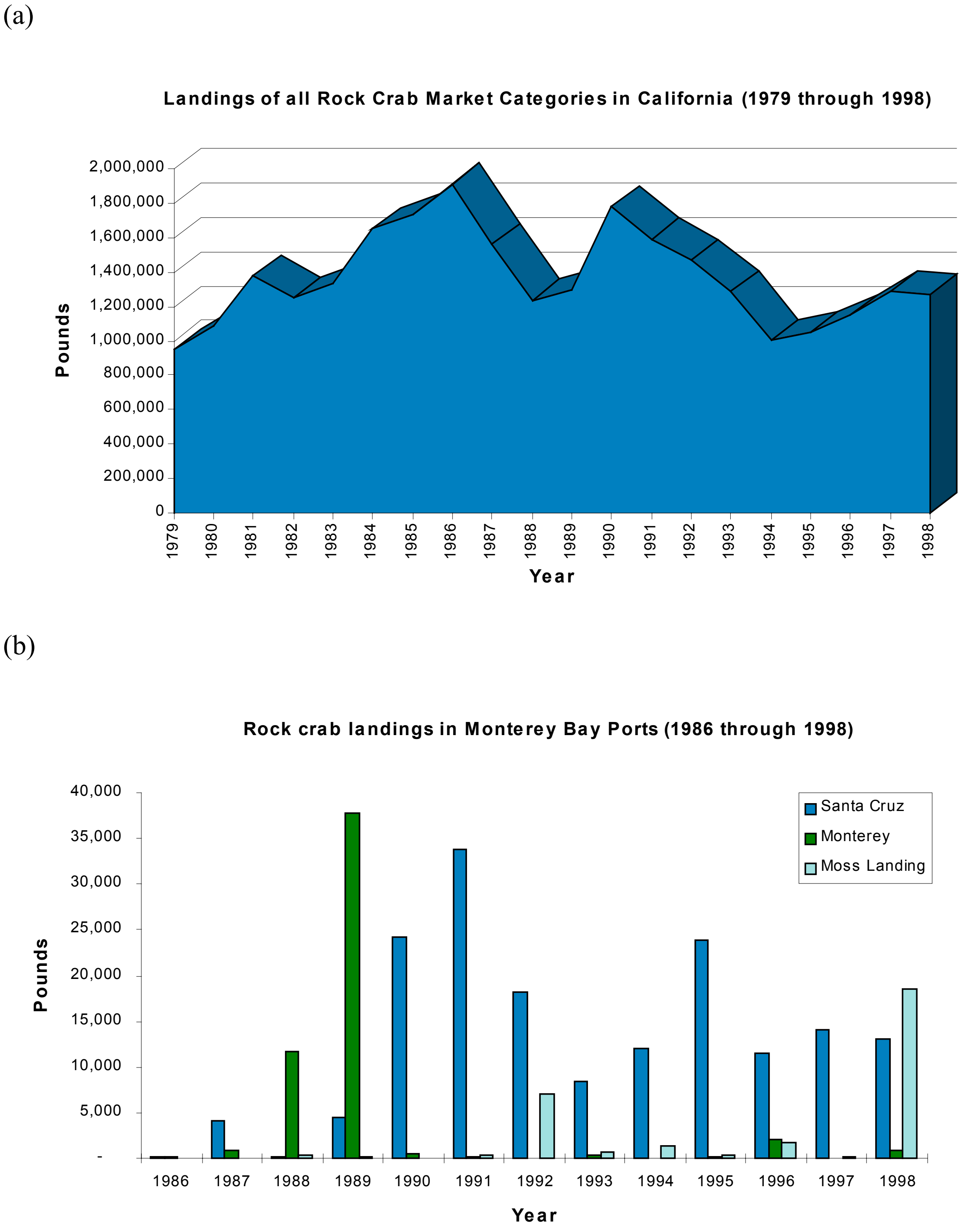
Information on the time required for egg development and hatching is not available for red rock crabs, however literature suggests that water temperature is an important variable for brown and yellow rock crabs (Anderson and Ford, 1976; Carroll, 1982). As with all decapod crustaceans, growth in rock crabs is an incremental process occurring only at the time of molting. Newly hatched larvae (prezoeal stage) molt to a first stage zoea in less than an hour (Carroll and Winn, 1989). Larval rock crabs undergo a series of 5 zoeal molts (size changes) and one megalopal molt before they bear any resemblance to the adults. Zoea and megalops are pelagic and are widely dispersed by wind and currents over the continental shelf (Carroll and Winn, 1989). Juvenile crabs begin to settle out of the water column (following the megalopal molt) during the late spring and summer (Winn, 1985).

Molting events separate the various post-larval stages, or instars, in the life of a crab. Because of their rigid exoskeleton, increases in the body dimensions of a crab can occur only after molting. Rock crab growth is characterized as indeterminate because molting and growth progress indefinitely (no terminal molt) until the animal dies. The period of time between molts (intermolt period) lengthens as the size of an animal increases and the proportional growth (width and weight increase) from each molt tends to decrease (Carroll, 1982; Carroll and Winn, 1989). Water temperature is among the factors reported to have an effect on the growth rate of post-larval crabs (Anderson and Ford, 1976). While animals up to 76 mm (3 in.) carapace width (CW) may molt 2 or more times in a year, the intermolt periods of crabs in their later instars may last 16 months or longer (Carroll, 1982; Parker, 1992). The maximum age attained by each of the rock crab species is not well defined in literature but estimates (based on size and growth curves) suggest that some individuals may live for at least 6 years (Carroll, 1982; Carroll and Winn, 1989).

Rock crabs are generalist carnivores and assume the role of both a predator and a scavenger. They actively forage for a variety of sessile and mobile animals including snails, clams, echinoderms, and crustaceans (Carroll and Winn, 1989). Because of their powerful chelae (claws), adult rock crabs have the ability to crush and consume a thick-shelled mollusks (gastropods and bivalves) like cockles *Protothaca staminea* (Boulding, 1984; Boulding and LaBarbera, 1986), mussels *Mytilus* spp. (Smith and Palmer, 1994; Dugan, pers. obs., 1997), and abalone *Haliotis* spp. (Schiel and Welden, 1987). They also consume crustaceans such as hermit crabs (Morris et al., 1980; Ricketts et al., 1985), barnacles *Balanus* spp. (Ricketts et al., 1985), and a variety of crab species including smaller, or newly molted (soft), rock crabs. Cannibalism has been observed in the closely related dungeness crab (Gotshall, 1977). Food preferences during laboratory culture indicate that rock crabs are active planktivores during their larval stages (Rumrill et al., 1985). Rock crabs also have a highly developed ability to sense the presence of food in the vicinity (Carroll and Winn, 1989). Amino acid concentrations as low as 10^{-11} moles/liter can be detected by the animals olfactory apparatus (Fuzessery and Childress, 1975).

Rock crabs are vulnerable to predation throughout their lives. However, the risk is greatly diminished in adult crabs. A host of planktivorous fishes and invertebrates consume pelagic rock crab larvae. As juveniles, rock crabs are preyed upon by a variety of fishes as well as some invertebrate species. The scorpionfish *Scorpaena guttata*, cabezon *Scorpaenichthys marmoratus*, barred sand bass *Paralabrax nebulifer*, and a number of rockfish species *Sebastes* spp. are among the many piscine predators of juvenile rock crabs (Turner et al., 1969; Roberts et al., 1984; Winn, 1985, Carroll and Winn, 1989). The sand star *Astropecten verilli* is known to prey on juvenile yellow rock crabs (Van Blaricom, 1978, 1982). One of the primary predators of adult rock crabs is the southern sea otter *Enhydra lutris* (Carroll, 1982; Benech, 1986). Rock crab are also a favored prey item of octopi (Ambrose, 1984) and are consumed by some shark species (Talent, 1982). Larger rock crabs are vulnerable to predation by fishes and to cannibalism during the “soft-shelled” period following a molt (Knowles and Carlisle, 1956; Carroll, 1982).

Rock crabs have not been the focus of a dedicated commercial fishery until relatively recently. Historically they were considered bycatch in trap fisheries targeting more valuable species and were either thrown back into the sea or left on the shore to die (Dahlstrom and Wild, 1983; Winn, 1985). Small rock crab landings have been reported since at least the 1930’s, however, a separate market category was not established for the group until 1950 (Parker, 1992). Annual rock crab landings of around 20,000 pounds were reported in 1950 (Heimann and Carlisle, 1970; Carroll and Winn, 1989; Parker, 1992). The fishery grew at an annual rate of about 10 percent from the late 1950s until 1971 (Parker, 1992). Landings nearly doubled in 1972 and by 1975 had surpassed 1 million pounds for the first time (Parker, 1992). State-wide landings from 1979 through 1998 and landings from Monterey Bay ports from 1986 through 1998 are shown in Figure 4-39. During the past two decades rock crab landings have averaged over 1.3 million pounds annually (Figure 4-39) (CDFG Landing Summaries, 1979–1998). Commercial fishermen generally receive around $1.00 per pound for whole, live rock crab (Parker, 1992).



Source: CDFG Landing Summaries 1979–1998.

Figure 4-39. (a) California state-wide landings (lbs) of rock crabs (includes the rock crab market categories of unspecified rock crabs, brown rock crab, red rock crab, and yellow crab): 1979 through 1998. (b) Ports of Monterey Bay landings (lbs) of the market category “Unspecified Rock Crab”: 1986 through 1998.

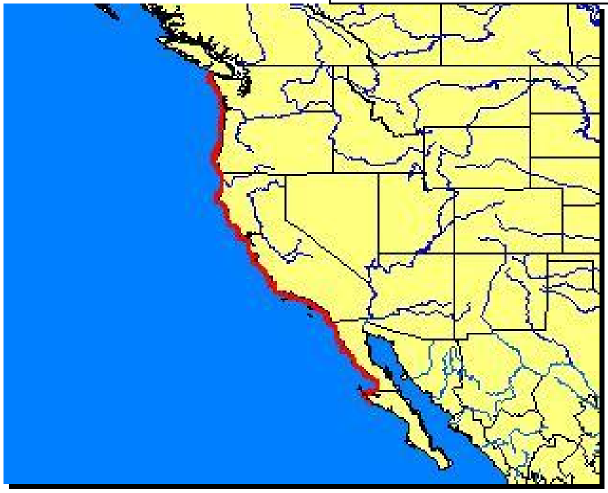
In addition to landings of whole rock crab, rock crab claws are landed by gillnet fishermen who catch them incidentally, de-claw them and return them to the ocean. While rock crab claws were included in the crab claw market category, the majority of landings were composed of the claws of sheep crab *Loxorhynchus grandis* (D. Parker, CDFG, pers. comm.). Estimates of the percentage of rock crab claws in these landings are not available. Crab claw landings have declined significantly since the early 1990s when depth restrictions for gillnet use went into effect.

The species composition of landings of whole rock crabs is not available because they have historically been landed in a combined market category (Unspecified Rock Crab) and not separated by species; some separation by species has occurred since 1995. However, the bulk of the landings are still grouped into the "Unspecified Rock Crab" market category. Trapping studies have provided some insight into variations in the seasonal abundance of each species and regional differences in species composition (Selby, 1980; Carroll, 1982; Carroll and Winn, 1989).

4.12 Hairy Rock Crab *Cancer jordani*

Cancer jordani

Picture to come



Distribution Map for Hairy Rock Crab

Range: From Neah Bay, Washington to Bahía de Tortuga, Baja California.

Life History: Size: males up to 39.3 mm (1.5 in.); females to 19.5 mm (0.7 in.); Size at maturity: no information available; Fecundity: no specific information available; life span: no estimate available.

Habitat: Under rocks in shallow bays, subtidally in kelp holdfasts; intertidally to depths of 104 m (340 ft).

Fishery: No commercial or recreational fishery.

The hairy rock crab is one of the smallest members of the Family Cancridae. The species ranges from Bahía de Tortuga, Baja California, Mexico to Neah Bay, Washington, although it is rare north of Coos Bay, Oregon (Jensen, 1995). Hairy rock crab occur from the intertidal zone down to depths of 104 m (340 ft) (Garth and Abbott, 1980). They are most often observed under rocks in the shallow waters of bays, but may also be found subtidally in the holdfasts of kelp. In Monterey Bay, up to 78 hairy rock crab have been documented per m^2 of kelp holdfast (Garth and Abbott, 1980).

The carapace of the hairy rock crab is similar in shape to other cancer crabs and has a smooth but somewhat irregular surface. The legs and dorsal surface of the carapace are covered with hair. The hairy rock crab may be confused with juvenile brown rock crab *C. antennarius*, which often have a hairy appearance (Carroll and Winn, 1989). Another small cancer crab, the furrowed rock crab *Cancer branneri*, also has hair covering its carapace and legs. Hairy rock crabs do not have the red ventral spotting present in juvenile *C. antennarius* (Carroll and Winn, 1989). The species also has ten teeth lining the anterior margin of the carapace, instead of nine as in *C. antennarius* (Garth and Abbott, 1980). The anterolateral teeth of hairy rock crab are sharp and strongly curved, and are alternately large and small (Garth and Abbott, 1980; Carroll and Winn, 1989; Jensen, 1995). Dorsally, the carapace of the hairy rock crab is dark brown or reddish in color and often mottled in appearance (Jensen, 1995). Ventral surfaces are light and uniform in coloration. The fingers of the claws are dark-tipped (Jensen, 1995). The hairy rock crab is a small *Cancer* species with males measuring up to 39.3 mm (1.5 in.) and females to 19.5 mm (0.7 in.) (Jensen, 1995). The life span of the species and the age/size at maturity is unknown.

Information on the life history of the hairy rock crab is scarce. Reproductive behavior can be assumed to follow the pattern of other cancer crabs. Ovigerous females have been found in Monterey Bay during October and November. The eggs and larvae of hairy rock crab are similar in size to those of larger rock crab species (J. Carroll, Tenera, pers. comm.). Hairy rock crab larvae have been reported to be larger than those of *C. antennarius* in the same stage (J. Carroll, Tenera, pers. comm.). Because of the small size of adult female hairy rock crab, and the proportionally large size of individual eggs, it has been suggested that the species is probably less prolific than larger *Cancer* species (J. Carroll, Tenera, pers. comm.). Based on these observations, the fecundity would probably be on a scale of thousands or tens of thousands of eggs instead of the hundreds of thousands or millions typical of larger cancer crab species. It is likely that the larval, juvenile, and adult hairy rock crab are preyed upon by the same assemblage of fishes and invertebrates that consume the larvae and early crab stages of other *Cancrid* species. Because of their small size, adult hairy rock crab probably remain vulnerable to predation by fish species such as cabezon *Scorpaenichthys marmoratus* and rockfishes *Sebastes* spp., and small octopi *Octopus* spp. throughout their lives. The species is not harvested commercially or recreationally.

4.12.1 Hairy Rock Crab Results (29.3 percent)

Hairy rock crab comprised 29.3 percent of the total number of entrained megalops at the new CC units intake (Figure 4-1). They were collected in 12 of the 42 entrainment surveys (Figure 4-40). They were collected from the end of August 1999 through mid-October 1999 and again from mid-November 1999 through the beginning of December 1999. They were collected again in late December 1999, mid-January and mid-February 2000. The peak concentration (63/1,000 m^3) occurred on September 30, 1999 all remaining concentrations were below 11/1,000 m^3.

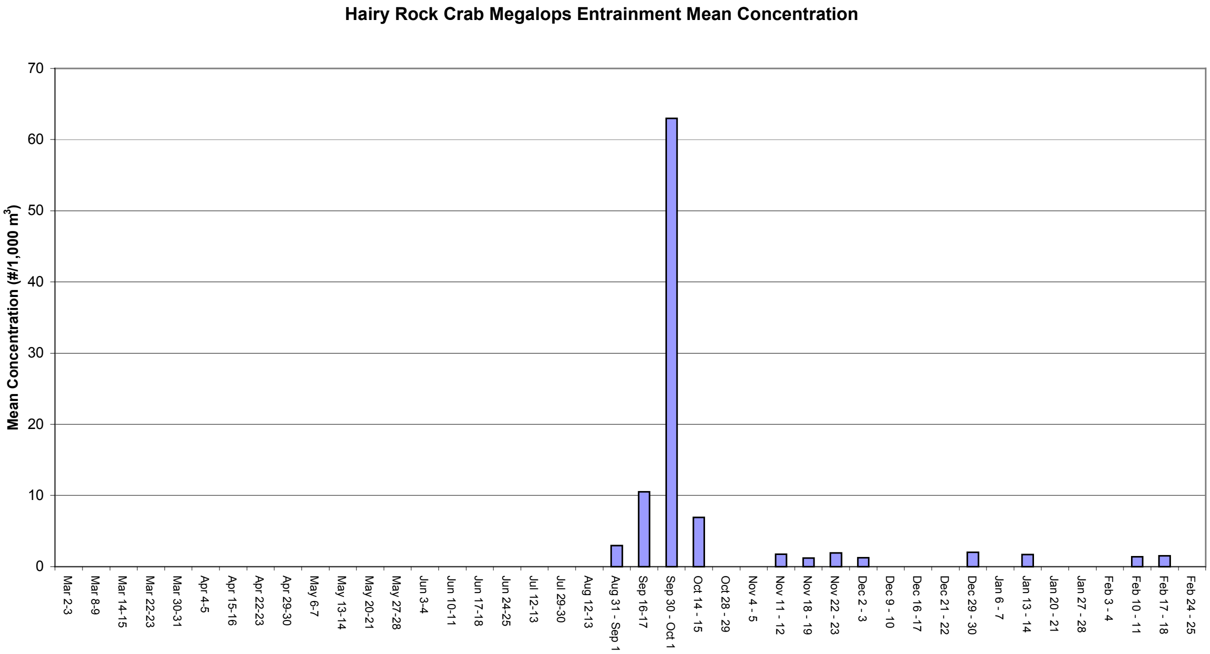
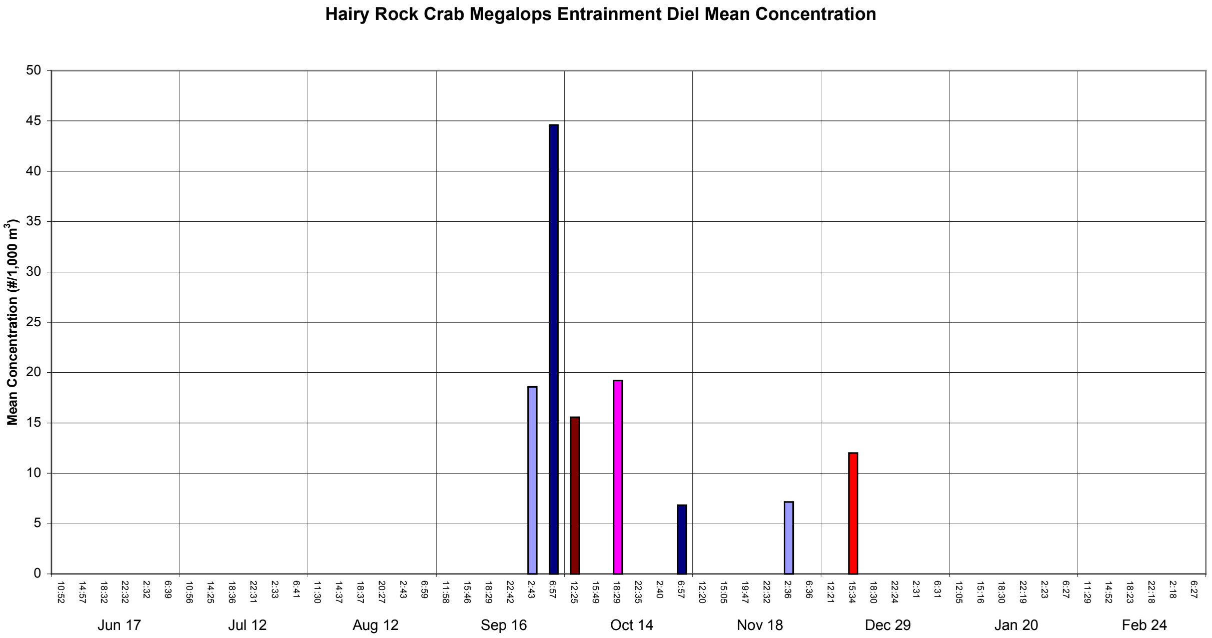


Figure 4-40. Mean survey concentrations (#/1,000 m^3) of hairy rock crab megalops at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

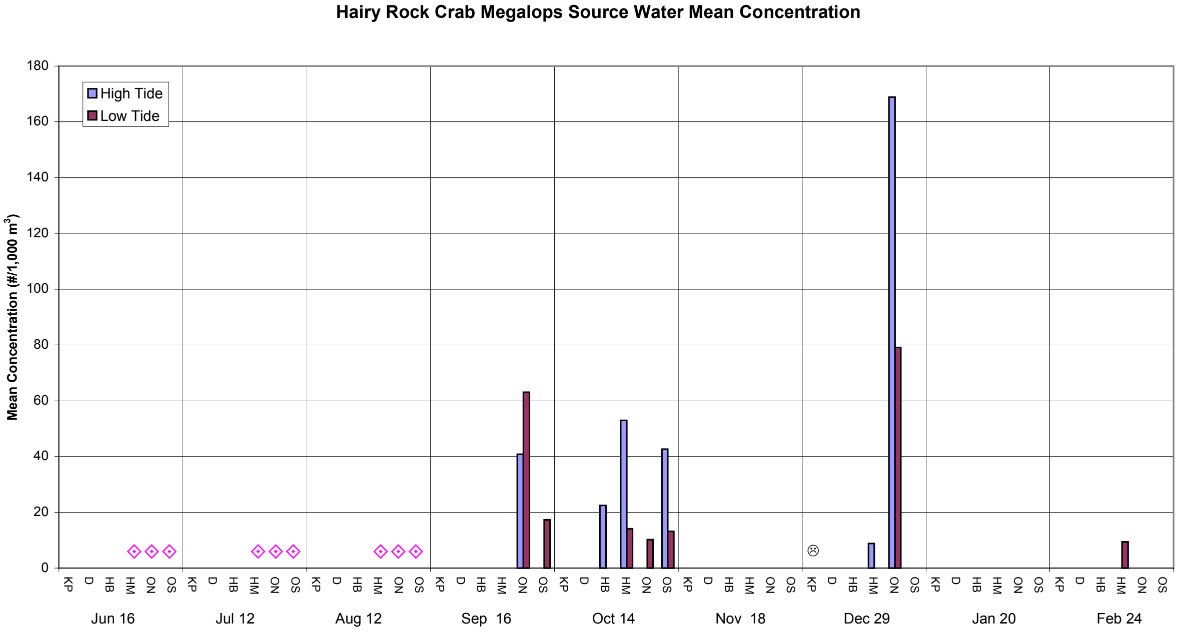
The diel distributions were plotted for concentrations of hairy rock crab megalops. We analyzed only the entrainment surveys that coincided with source water surveys from June 1999 through February 2000. Hairy rock crab megalops were collected only during the September through December 1999 surveys (Figure 4-41). Concentrations were highest during the early morning in September 1999, during the nighttime in October and November 1999, and in the afternoon in December 1999.



Note: These entrainment surveys were conducted at the same time as the source water surveys. Data are preliminary.

Figure 4-41. Concentrations (#/1,000 m^3) of hairy rock rock megalops at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Hairy rock crab megalops were collected in the September, October, December 1999, and February 2000 source water surveys (Figure 4-42). Peak concentrations occurred during the high and low tides (169/1,000 m3 and 79/1,000 m^3, respectively) at the Ocean North Station on December 29, 1999. Hairy rock crab megalops were collected predominately at Ocean North, Ocean South, and Harbor Mouth stations. They were never collected at the Kirby Park, Dairies and collected only once in October 1999 at the Harbor Bridge.



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

◇ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-42. Source water concentrations (#/1,000 m^3) of hairy rock crab megalops at six stations near Moss Landing Power Plant: June 1999 through February 2000.

4.13 Yellow Rock Crab *Cancer anthonyi*

Photographer: Dan Dugan

Cancer anthonyi

Distribution Map for Yellow Crab

***Range*:** From Humboldt Bay, California to Bajia Magdalena, Baja California.

***Life History*:** Adult crabs sexually dimorphic; size: males to 176 mm (6.9 in.), females reach 144 mm (5.6 in.); size at maturity: 90 to 100 mm (3.5 to 3.9 in.) for laboratory-reared animals; fecundity: 680,000 to 3.85 million eggs; life span: no estimate available.

***Habitat*:** Soft substrates such as sand, sandy-silt, and mud; occur in the vicinity of rock reefs or artificial structures; the lower intertidal zone to depths exceeding 130 m (427 ft).

***Fishery*:** Moderate commercial fishery, small recreational fishery.

The yellow crab *Cancer anthonyi* Rathbun occurs along the Pacific Coast of North America from Humboldt Bay, California to Bajia Magdalena, Baja California (Jensen, 1995). Within this range their distribution is almost exclusively associated with sand substrata (Winn, 1985; Carroll and Winn, 1989). The species is most abundant on the expanses of open, sandy substrata that characterize much of the Southern California Bight. It is, however, also commonly encountered near the rock-sand interface of natural and artificial reefs in the region (Morris, 1980; Carroll and Winn, 1989). Yellow crab are also common underneath and in the vicinity of offshore oil and gas platforms south of Point Conception (Page et al., 1999). In the northern parts of their range, where rocky benthic substrata predominate, their distribution appears to be confined more to bays, sloughs, and estuaries (Jensen, 1995). Yellow rock crab occur from the lower intertidal zone to depths exceeding 130 m (427 ft) but are most commonly found in depths between 18 to 55 m (59 to 180 ft) (Morris et al., 1980; Winn, 1985; Carroll and Winn, 1989; Jensen, 1995). They are the most abundant cancer crab species harvested in southern California, often composing 70 to 95 percent of the total crab catch in the region (Carroll and Winn, 1989). During diver surveys of yellow rock crab populations in Santa Monica Bay it was noted that the species was never seen during daylight hours in the vicinity of traps, but were often abundant in the traps the next morning (R. Hardy, CDFG, pers. comm.). These observations suggest that yellow rock crab are nocturnally active in shallow water and remain buried and inactive during daylight hours.

The carapace of the yellow rock crab is similar in shape to that of the brown rock crab, but is proportionally larger and convex dorsolaterally (domed). Its surface is smooth and there are ten anterolateral teeth extending along the anterior margin of each side of the body. The anterolateral teeth are wider and less acute than those of the brown rock crab. The carapace is widest between the ninth anterolateral teeth (Carroll and Winn, 1989). Dorsally, the yellow rock crab varies from light brown to yellow or orange in color (Carroll and Winn, 1989; Jensen, 1995). Ventral surfaces are a uniform light yellow with no red speckling (Carroll and Winn, 1989). The walking legs are also yellow or orange in color and generally do not have hair (Carroll and Winn, 1989; Jensen, 1995). The tips of the claws are dark (Carroll and Winn, 1989).

Like the brown rock crab, adult yellow rock crab are sexually dimorphic, with males attaining a larger size and growing larger, more robust chelae (claws). Male crabs grow to a maximum size of 176 mm (6.9 in.) while females reach 144 mm (5.6 in.) (Jensen, 1995). No estimates of the life span of yellow rock crab were cited in the literature reviewed. A laboratory-reared female yellow crab became sexually mature after molting to the thirteenth instar (Anderson and Ford, 1976). The molt occurred when the crab was 400 days old and had a post-molt carapace width of 98 mm (3.86 in.) (Anderson and Ford, 1976).

Ovigerous female yellow rock crabs are found throughout the year (Toole, 1985; Winn, 1985; Reilly, 1987), however, they are most common during the winter and spring months (Reilly, 1987). The size of a female's egg mass is variable and can contain from 680,000 to 3.85 million eggs (Carroll and Winn, 1989). The clutch size in yellow rock crabs is reported to average 2.6 million eggs (Carroll and Winn, 1989). Development of the eggs and subsequent hatching takes 7 to 8 weeks at ambient temperatures of 10° to 18° C (50° to 64° F) (Anderson and Ford, 1976; Carroll, 1982). Yellow rock crab eggs have hatched in 43 days at a constant temperature of 17° C (63° F) (Carroll and Winn, 1989). Larval development was accelerated significantly by a water temperature increase of 4° C (7.2° F) from 18° to 22° C (64° to 72° F) (Anderson and Ford, 1976). Because of the shortened duration of each instar at 22° C (72° F), the total time required for larval development was cut to 33 days as compared with 45 days at 18° C (64° F) (Anderson and Ford, 1976). Differences in post-larval growth in yellow crabs have been attributed to water temperature (Anderson and Ford, 1976).

4.13.1 Yellow Rock Crab results (19.6 percent)

Yellow rock crab comprised 19.6 percent of the total number of entrained *Cancer* spp. megalops at the new CC units intake (Figure 4-1). They were collected in all CC units intake entrainment surveys from November 4, 1999 through December 21, 1999 and again in the January 13 and 20, 2000 surveys (Figure 4-43). The highest concentrations occurred in December 1999 (peak concentration, 16.3/1,000 m^3 on December 16, 1999). All other concentrations were below 3.4/1,000 m^3.

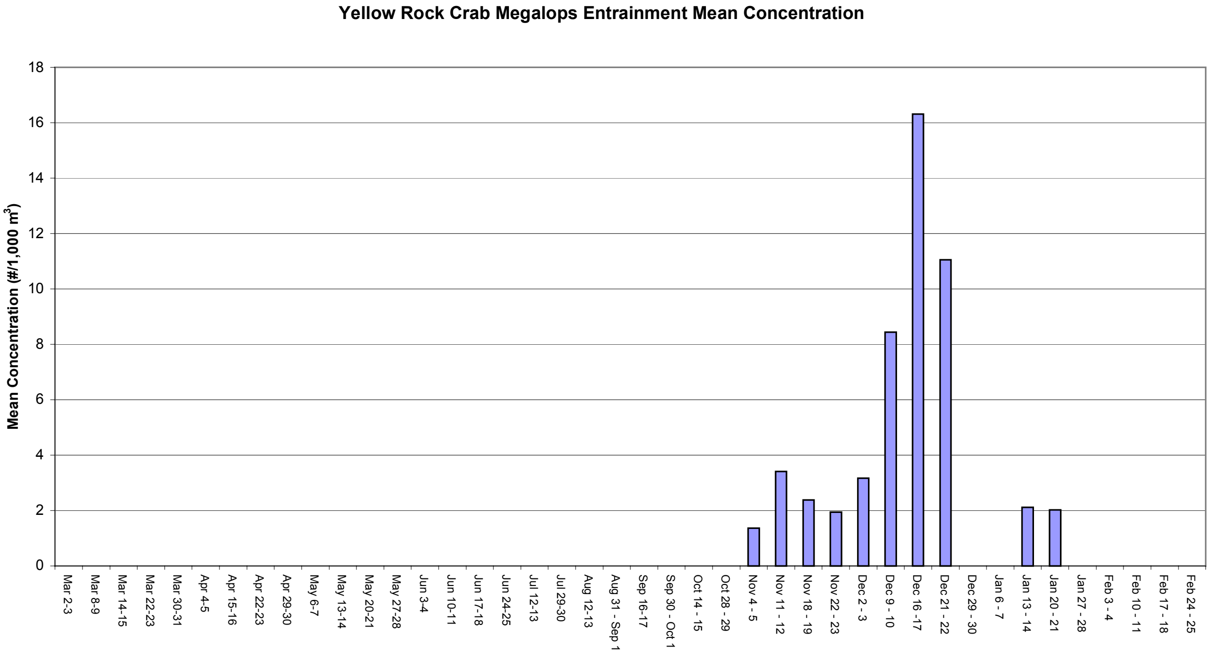
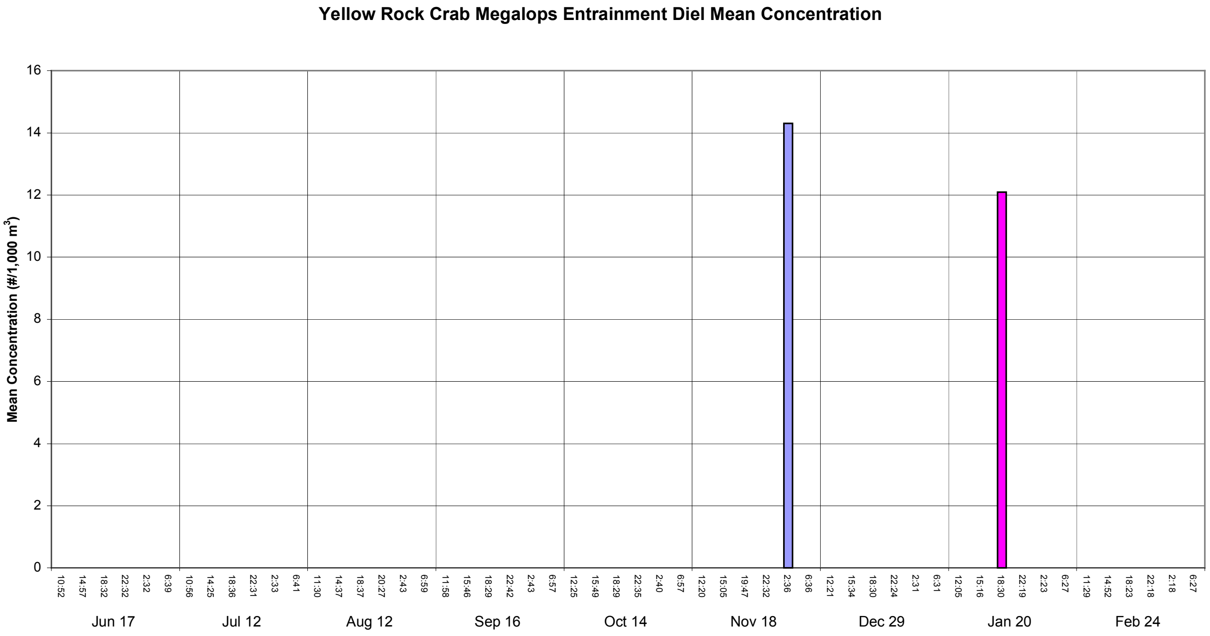


Figure 4-43. Mean survey concentrations (#/1,000 m^3) of yellow rock crab megalops at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

The diel distributions were plotted for concentrations of yellow rock crab megalops. We analyzed only the entrainment surveys that coincided with source water surveys from June 1999 through February 2000. They were collected only in the November 1999 and January 2000 surveys during one cycle at night (0236 and 1830 hours PST, respectively) (Figure 4-44).

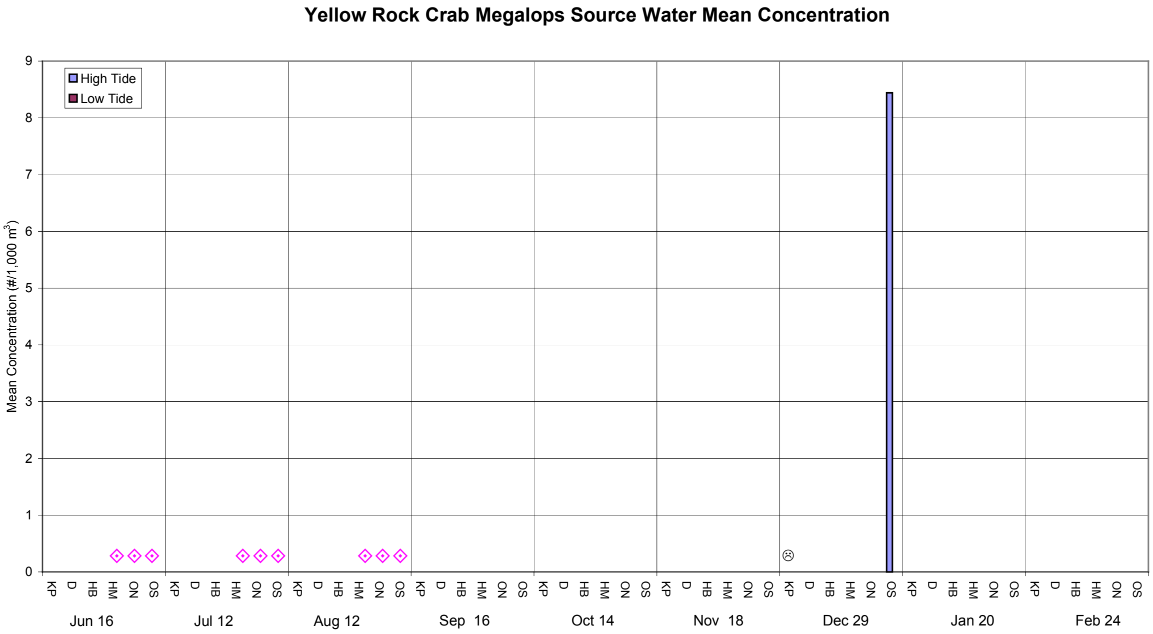


Yellow Rock Crab Megalops Entrainment Diel Mean Concentration

Note: These entrainment surveys were conducted at the same time as the source water surveys. Data are preliminary.

Figure 4-44. Concentrations (#/1,000 m^3) of yellow rock crab megalops at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Cancer anthonyi megalops were only collected at the Ocean South Station during a high tide (concentration = 8.4/1,000 m^3) on December 29, 1999 (Figure 4-45).



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

◇ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-45. Source water concentrations (#/1,000 m^3) of yellow rock crab megalops at six stations near Moss Landing Power Plant: June 1999 through February 2000.

4.14 Brown Rock Crab *Cancer antennarius*


Photographer: Dan Dugan

Cancer antennarius


Distribution Map for Brown Rock Crab

Range**:** From Queen Charlotte Sound, British Columbia to Cabo San Lucas, Mexico.

Life History**:** Adult crabs sexually dimorphic; size: males to 178 mm (7 in.), females to 148 mm (5.8 in.); size at maturity: 60 to 80 mm (2.4 in. to 3.1 in.); fecundity: 410,000 to 2.79 million eggs; life span: estimated to be 5 to 6 years.

Habitat**:** A variety of substrates including rock, gravel, sand, and sandy-silt. Occurs from the lower intertidal to depths exceeding 100 m (328 ft.)

Fishery**:** Small recreational fishery; moderate commercial fishery.

The Pacific or brown rock crab *Cancer antennarius* Stimpson is distributed in nearshore waters along the Pacific Coast of North America from Queen Charlotte Sound, British Columbia to Cabo San Lucas, Mexico (Jensen, 1995). Although it is reported to be abundant in Barkley Sound, British Columbia (Jensen, 1995), the species range of peak abundance extends from San Francisco Bay to coastal areas south of the U.S.-Mexico border (Carroll and Winn, 1989). Brown rock crab are a marine species that inhabit nearshore coastal regions but may also be found in sloughs and estuaries. They are, however, unable to osmoregulate and do not tolerate brackish conditions well (Garth and Abbott, 1980). Brown rock crab inhabit a variety of substrates including rock, gravel, sand, and sandy-silt (Winn, 1985). They occur from the lower intertidal zone to depths exceeding 100 m (328 ft) but are typically found near the rock-sand interface in depths of less than 55 m (180 ft) (Carroll and Winn, 1989). Juvenile brown rock crab inhabiting the intertidal zone survive exposure to the air during low tide by sheltering themselves under rocks and algae (Ricketts, 1985).

The carapace of the brown rock crab is generally oval in shape and relatively flat dorsolaterally with an irregular but otherwise smooth surface. Nine anterolateral teeth line the anterior margin of the carapace on each side of the body. The carapace is widest between the eighth anterolateral teeth (Carroll and Winn, 1989). The dorsal surface of the carapace is generally a mottled brown color but may range from orange-red to gray. Ventral surfaces are light (white to cream) in coloration with reddish speckling (Carroll and Winn, 1989). The red speckling on the ventral surfaces is a distinguishing characteristic of the species and is not present on other cancrid crabs. Another distinguishing characteristic of the species is the two pairs of antennae (one long, one short and stout) that originate between the retractable eye stalks (Carroll and Winn, 1989). The walking legs of brown rock crabs may be hairy, especially in juveniles and females (Carroll and Winn, 1989). Adult crabs are sexually dimorphic, with males attaining a larger size and growing larger more robust chelae (claws). Male crabs grow to a size (maximum carapace width [CW]) of 178 mm (7 in.) while females reach 148 mm (5.8 in.) (Jensen, 1995). The life span of brown rock crab is estimated to be 5 to 6 years (Carroll, 1982).

Ovigerous female brown rock crabs are found throughout the year (Toole, 1985; Winn, 1985; Reilly, 1987) however, they are most common during the winter months (Carroll, 1982). The size of a female's egg mass is variable and can contain from 410,000 to 2.79 million eggs (Carroll and Winn, 1989). Development of the eggs and subsequent hatching takes 7 to 8 weeks at temperatures of 10° to 18° C (50° to 64° F) (Anderson and Ford, 1976; Carroll, 1982). Size (CW) increases in the brown rock crab range from 7 to 26 percent per molt, while increases in body weight of 50 to 70 percent have been measured (Carroll, 1982). The sexes undergo a molt to maturity (50 percent maturity value of population using Somerton, 1980 method) from between 60 mm and 80 mm (CW) (2.4 in. and 3.1 in.) (Carroll, 1982). Brown rock crabs are estimated to go through 10 to 12 molts before reaching sexual maturity (Parker, 1992).

4.14.1 Brown Rock Crab Results (19.0 percent)

Brown rock crab comprised 19.0 percent of the total number of entrained *Cancer* spp. megalops at the new combined-cycle units intake (Figure 4-1). They were collected in 14 of the 42 entrainment collections at the new combined-cycle units intake (Figure 4-46). Highest concentrations occurred in two surveys in September 1999 (both concentrations were approximately 9/1,000 m^3) and again in January 2000 (9.5/1,000 m^3). All other concentrations from the new CC units intake entrainment surveys were below 5.1/1,000 m^3.

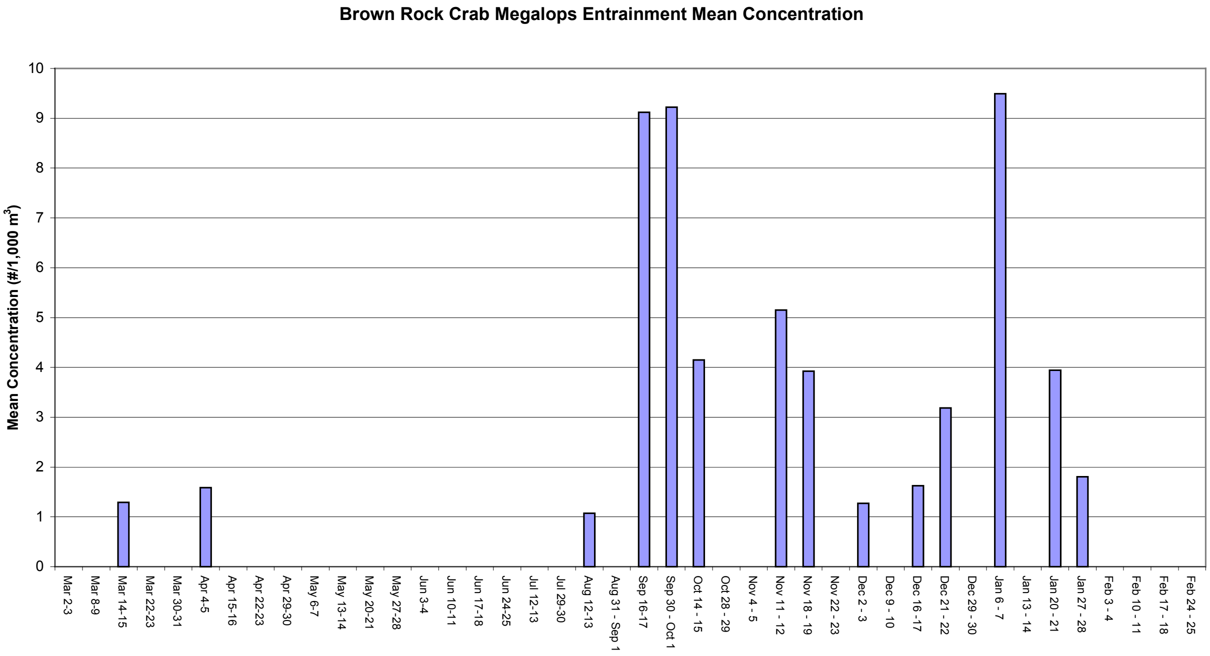
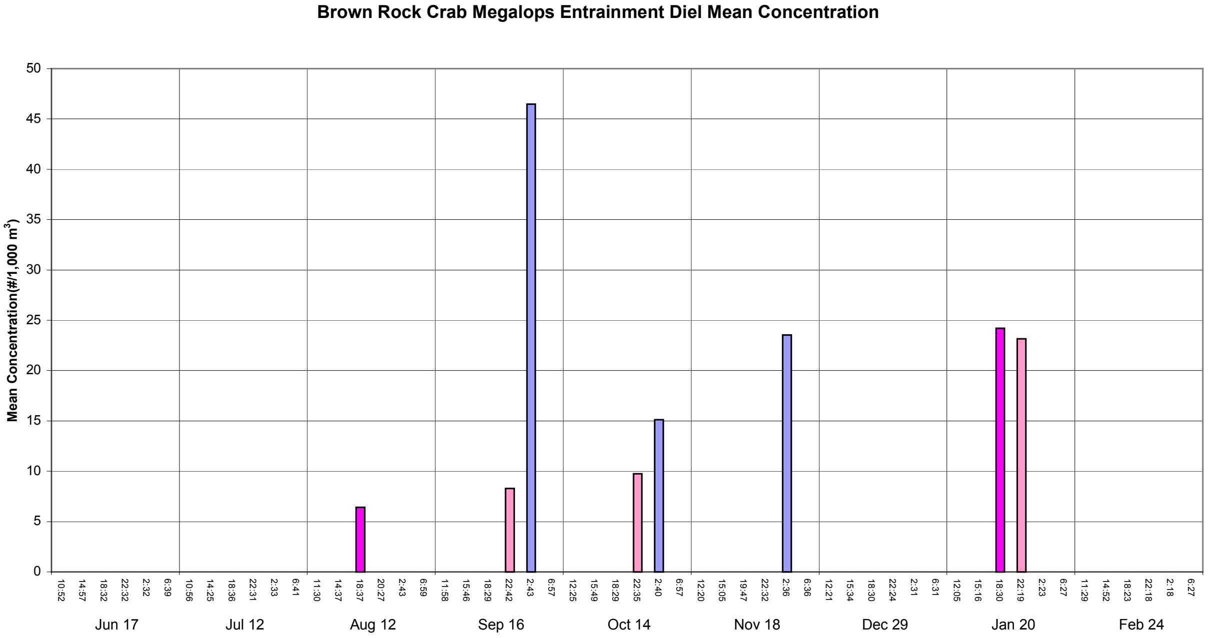


Figure 4-46. Mean survey concentrations (#/1,000 m^3) of brown rock crab megalops at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

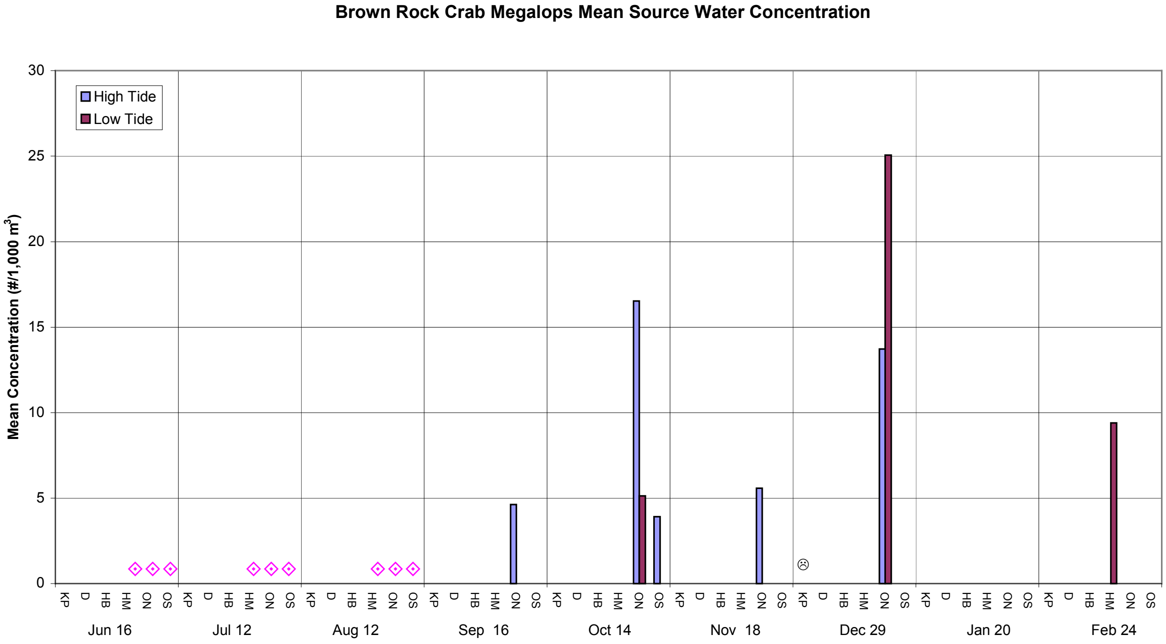
The diel distributions were plotted for concentrations or brown rock crab megalops. We analyzed only the entrainment survyes that coincided with source water surveys from June 1999 through February 2000. They were collected in the August through November 1999 and the January 2000 entrainment surveys. The highest concentrations occurred at approximately 0240 hours PST during the September through November 1999 surveys. In January 2000 they were only collected at nighttime at 1830 and 2219 hours PST (Figure 4-47).



Note: These entrainment surveys were conducted at the same time as the source water surveys. Data are preliminary.

Figure 4-47. Concentrations (#/1,000 m^3) of brown rock rock megalops at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Brown rock crab megalops were predominately collected at the Ocean North and Ocean South stations (Figure 4-48). Peak concentration (25.1/1,000 m^3) occurred on a low tide at the Ocean North station on December 29, 1999. They were only collected at the Harbor Mouth Station during a low tide on February 24, 2000. They were never collected at the Kirby Park, Dairies, or Harbor Bridge stations from June 1999 through February 2000.



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

⟐ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-48. Source water concentrations (#/1,000 m^3) of brown rock crab megalops at six stations near Moss Landing Power Plant: June 1999 through February 2000.

4.15 Dungeness Crab *Cancer magister*

Source: CDFG

Cancer magister

Distribution Map for Dungeness Crab

Range: From Pribilof Islands, Alaska to Point Conception, California.

Life History: Size: males to 230 mm (9 in.), females to 165 mm (6.5 in.); age at maturity: one and a half years; fecundity: 700,000 to 2.5 million eggs, spawns once a year; life span: to 8 years.

Habitat: Common subtidally to 90 m (295 ft); as deep as 230 m (750 ft).

Fishery: Recreational, large commercial market.

Dungeness crab occur in Pacific coastal waters from Pribilof Islands, Alaska to Point Conception near Santa Barbara, California (Jensen, 1995). They are one of the largest and most commercially important crabs along the Pacific Coast. The northern coast of California, including the Bodega Bay and San Francisco area, supports a sizable dungeness crab population, while smaller populations occur in the Monterey Bay and Morro Bay/Avila Beach area (Dahlstrom and Wild, 1983). Five sub-populations are reported to exist in California waters in the following areas: 1) Avila Beach/Morro Bay, 2) Monterey Bay, 3) San Francisco, 4) Fort Bragg to Cape Mendicino, and 5) Eureka/Crescent City (Garth and Abbott, 1980).

Dungeness crab are confined mainly to cold and temperate waters with annual mean temperatures ranging between 4° and 24° C (40° to 75° F) (Garth and Abbott, 1980). Adult dungeness crab commonly occur subtidally to 90 m (295 ft) residing on sandy bottoms and in eelgrass beds, but may be found as deep as 230 m (750 ft) (Jensen, 1995). Estuaries are important to their life cycle, and dungeness crab are thought to inhabit all estuaries from Morro Bay, California to Puget Sound, Washington (PSMFC, 1999).

Dungeness crab are beige to light brown on top and light orange to cream below; coloration varies little between individuals except for a slight purple to blue contrast in their claws and legs (Jensen, 1995). Male dungeness crab can measure up to 230 mm (9 in.) in carapace width, however they are more commonly found measuring less than 190 mm (7.5 in.). Carapace width in females is approximately 165 mm (6.5 in.) (Garth and Abbott, 1980).

Mating of dungeness crab, between hard-shelled males and soft-shelled (recently molted) females, occurs in the near-shore ocean in the vicinity of estuaries. On the central coast of California, mating occurs from March through May (Wild and Tasto, 1983). The females hold sperm internally until September to November at which time spawning begins and lasts through December (Garth and Abbott, 1980). The eggs are fertilized and the sponge-like mass of 700,000 to 2.5 million eggs is carried on the female's abdomen until late-December (Wild and Tasto, 1983) through February (Garth and Abbott, 1980). Eggs start hatching in December and reach a peak in March (Garth and Abbott, 1980).

After hatching, dungeness crab exist in a pre-zoeal stage for approximately 10 to 15 minutes (Reilly, 1983). During the next 105 to 125 days, larval development of dungeness crab progresses through five zoeal stages (approximately 80 to 95 days) to a megalopal stage (approximately 25 to 30 days) (Wild and Tasto, 1983). Sizes range from approximately 2.5 mm (0.25 in.) for stage one zoeae to 11.0 mm (0.43 in.) for megalopae (Poole, 1966). All larval stages are planktonic and the zoeae tend to make vertical diel migrations which keep them in the top 15 to 25 m (49 to 82 ft) of the water column by day and in surface waters by night (Reilly, 1983). The surface currents carry the larvae offshore, causing more late stage zoeae to be distributed farther out to sea than the early stage zoeae (Wild and Tasto, 1983).

In California waters, megalopae transform into juvenile dungeness crab in April through June. Young megalopae travel toward the coast with the aid of tidal currents and also by attaching themselves to the bells of jellyfish and the tentacles of *Velella velella* (Class Hydrozoa) (Garth and Abbott, 1980). The megalopae molt into first juvenile instars which then settle in shallow coastal waters, estuaries, and tidal flats. Living on eelgrass beds and other aquatic vegetation, the juveniles grow into adults through a series of molts; it takes approximately one and a half years and eleven to thirteen molts to reach maturity (Garth and Abbott, 1980; Wild and Tasto, 1983). After reaching maturity (at a carapace width of about 10 cm [4 in.]) dungeness crab molt and mate only once a year. The life span for dungeness crab is about eight years (Butler, 1961).

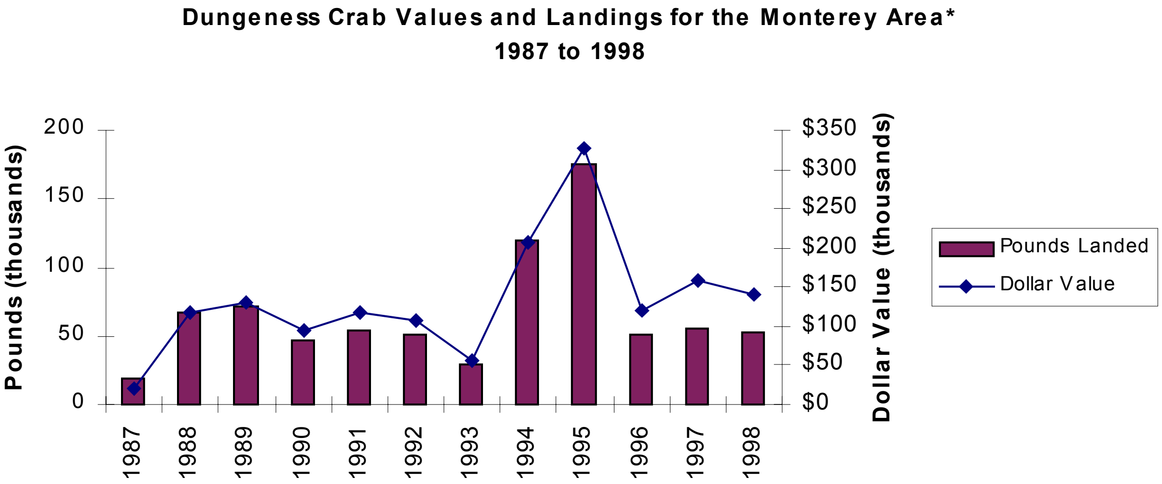
Dungeness crab are carnivorous, eating smaller crustaceans, shrimps, molluscs, clams, worms, and occasionally fishes. Dungeness crab are also an important prey species. Adult dungeness crab are eaten by harbor seals, sea lions, and humans. Crab larvae are eaten by Pacific herring, Pacific sardines, rockfishes, and salmon. Juvenile dungeness crab are fed upon by starry flounder, lingcod, rockfishes, sturgeon, English and rock sole, sharks, and skates (PSMFC, 1999). Marine worms, particularly *Carcinonemertes errans*, prey on the fertilized eggs of dungeness crab (Garth and Abbott, 1980).

The central California crab fishery began to decline in the early 1960's and the dungeness crab population still remains at low levels today. A number of factors have been investigated and suggested as to the cause of this decline. It is possible that pesticides, urban pollutants, and sewage have contributed to the mortality of larval and adult crabs (Garth and Abbott, 1980).

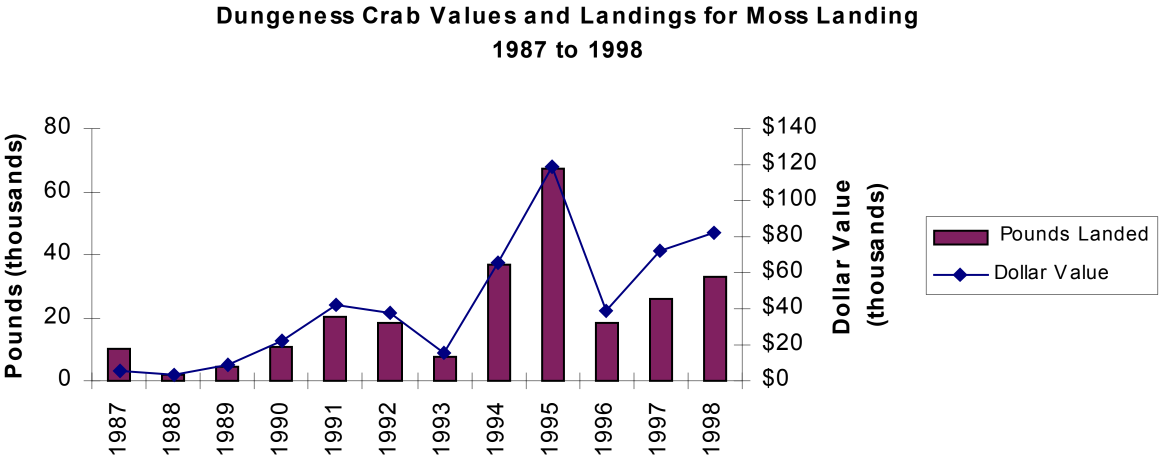
Dungeness crab cannot tolerate conditions of low dissolved oxygen. Contaminants, even in low concentrations, are highly toxic to dungeness crab. Predation on megalopae by Columbia River salmon has been suggested as a cause for the reduction in recruitment of crab along the central coast (Wild and Tasto, 1983). As large numbers of Coho salmon began to be successfully introduced from the Columbia River hatcheries, the dungeness crab population began to decline. The change in the ocean climate, including higher sea levels, increased water temperatures, and greater intensity of the Davidson Current, appears to have contributed to the dungeness crabs' decline. Higher water temperatures reduce egg survival and hatching success, and may limit ovary development. With the increase in the force of the Davidson Current, many crab larvae may be drifting northward, leaving central California with decreased recruitment (Wild and Tasto, 1983).

Dungeness crab landings throughout California have varied through the years. Landings were highest in the San Francisco area until the 1944 to 1945 season (Dahlstrom and Wild, 1983). Since that time, the majority of dungeness crab landings have been in northern California. The Morro Bay/Avila Beach and Monterey areas are in the southern part of the crab's range, and have never contributed significantly to the dungeness crab fishery. Figures 4-49a and b show reported commercial dungeness crab landings and values for the Monterey and Moss Landing areas from 1987 to 1998.

(a)



(b)



Source: CDFG Landing Summaries 1987–1998.

Figure 4-49. Dungeness crab landings (lbs) and value (dollars) of landings from 1987 through 1998 for (a) Monterey Bay ports* and (b) the port of Moss Landing.

(*includes Monterey, Moss Landing, and Santa Cruz).

4.15.1 Dungeness Crab Results (14.7 percent)

Dungeness crabs comprised 14.7 percent of the total number of entrained *Cancer* spp. megalops collected in the new CC units intake surveys. They were collected in all surveys from mid-April 1999 through June 3, 1999 (Figure 4-50). Peak concentration (10.1/1,000 m^3) occurred on May 20, 1999. The lowest concentrations (1.2/1,000 m^3) occurred on April 29 and May 27, 1999.

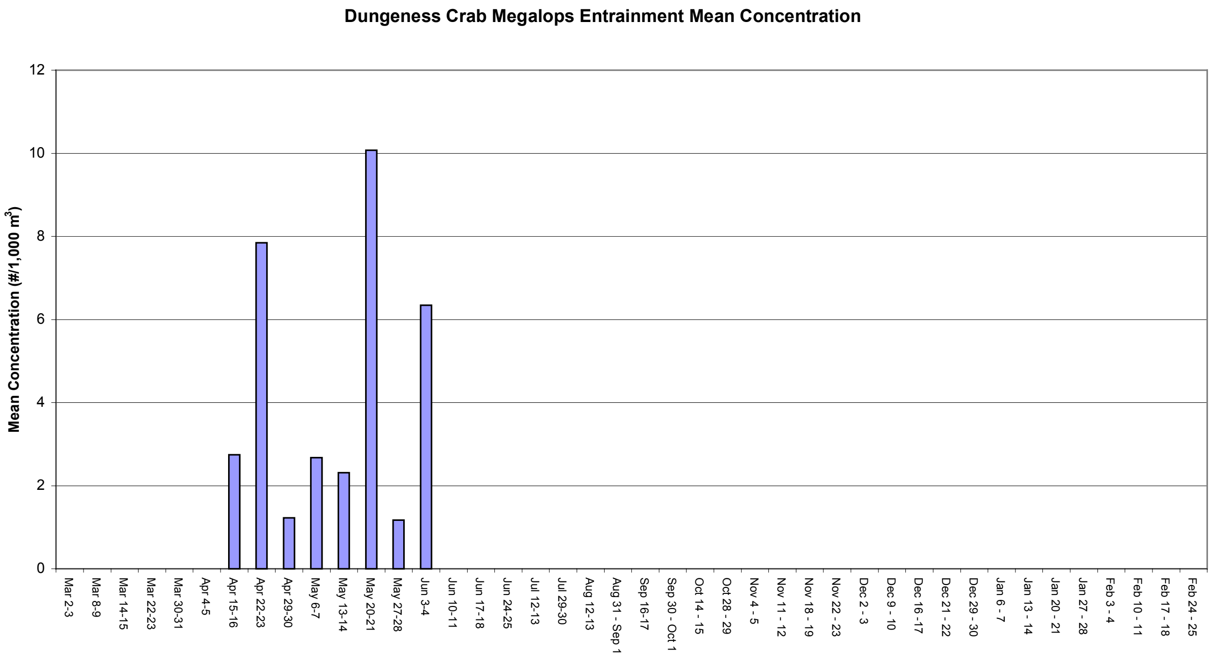


Figure 4-50. Mean survey concentrations (#/1,000 m^3) of dungeness crab megalops at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

Dungeness crab megalops were not collected at any source water stations from June 1999 through February 2000. It is important to note that source water collections did not begin until June 16, 1999 after the dungeness crab megalops were collected in entrainment surveys at the new combined-cycle units intake.

4.16 Red Rock Crab *Cancer productus*

Source: CDFG

Cancer productus

Distribution Map for Red Rock Crab

***Range*:** From Kodiak Island, Alaska to Isla San Martin, Baja California.

***Life History*:** Adult crabs sexually dimorphic; size: males to 200 mm (7.8 in.), females to 158 mm (6.2 in.); fecundity: 560,000 to 1.01 million eggs.

***Habitat*:** Hard substrate such as rocky reefs, well-protected boulder-strewn beaches, and gravel beds. Occur from the lower intertidal zone to depths of at least 91 m (299 ft).

***Fishery*:** Recreational; small commercial fishery.

The red rock crab *Cancer productus* Randall occurs along the Pacific Coast of North America from Kodiak Island, Alaska to Isla San Martin, Baja California (Jensen, 1995). Based on the low densities of red rock crabs collected during trapping studies in San Diego County, it is commonly contended that southern California defines the southern extent of the species range (Winn, 1989). The abundance of red rock crab, relative to the other rock crab species, increases with latitude within the state. Red rock crab inhabit a variety of substrata including intertidal and subtidal rocky areas, gravel, coarse sand, and mud (Carroll and Winn, 1989). They are commonly found in close association with hard substratum such as rocky reefs, well-protected boulder-strewn beaches, and gravel beds (Morris, 1980; Carroll and Winn, 1989; Jensen, 1995). Red rock crab occur from the lower intertidal zone to depths of at least 91 m (299 ft) (Winn, 1985; Carroll and

Winn, 1989). Juvenile red rock crab inhabiting the intertidal zone survive exposure to the air during low tide by sheltering themselves under rocks and algae (Ricketts, 1895). Red rock crab are often collected in bays, estuaries, and sloughs, however, their distribution in these areas is affected by salinity gradients because the species lacks the ability to osmoregulate (Garth and Abbott, 1980).

The carapace of the red rock crab is similar in shape but more laterally elongate than the carapace of brown rock crabs or yellow crabs. There are ten anterolateral teeth lining the anterior margins of the carapace along each side of the body. The carapace is widest between the eighth anterolateral teeth (Schmitt, 1921; Carroll and Winn, 1989). Anterolateral teeth are not equal in size in red rock crab and become larger and more acute posteriorly (Schmitt, 1921; Carroll and Winn, 1989). A shelf of 5 equally-spaced teeth protrudes between the eyes from the frontal margin of the carapace (Carroll and Winn, 1989). This shelf is one of the most distinguishing characteristics of the species at all sizes (Carroll and Winn, 1989). Adult red rock crabs are generally a uniform reddish color dorsally, but may also have a mottled appearance (Carroll and Winn; 1989, Jensen, 1995). Ventral surfaces are uniform in appearance and typically range from off-white to light yellow in coloration (Carroll and Winn, 1989). While there is no ventral speckling (red) in red rock crab, the dorsal surfaces of the walking legs may have a speckled appearance. The tips of the claws are dark (Carroll and Winn, 1989). Juvenile red rock crab are highly variable in dorsal coloration and display a wide array of patterns. The background dorsal coloration in juveniles may consist of variations of green, yellow, red, or white. Dorsal patterns include zebra-like stripes, multicolored bands, vermiculations, blotches, speckling, and uniform colors. Like the brown rock crab and yellow crab, adult red rock crab are sexually dimorphic, with males attaining a larger size and growing larger, more robust chelae (claws). Male crabs grow to a maximum size (CW) of 200 mm (7.8 in.), while females reach 158 mm (6.2 in.) (Jensen, 1995). No estimates of the life span of red rock crab were cited in the literature reviewed.

The size of a female’s egg mass is variable and can contain from 560,000 to 1.01 million eggs (Carroll and Winn, 1989). No information about the development and subsequent hatching of red rock crab eggs was available in reviewed literature. Trask (1970) found that red rock crab larvae developed to the megalopal stage in 97 days at a temperature of 11° C (52° F), however, none of his laboratory-reared larvae survived to the first crab instar.

4.16.1 Red Rock Crab Results (9.8 percent)

Red rock crab comprised 9.8 percent of the total number of entrained *Cancer* spp. megalops at the new CC units intake (Figure 4-1). They were collected in 12 of the 42 entrainment surveys (Figure 4-51). The peak concentration (8.3/1,000 m^3) occurred on May 20, 1999. Concentrations remained at or below 2.0/1,000 m^3 for all remaining surveys.

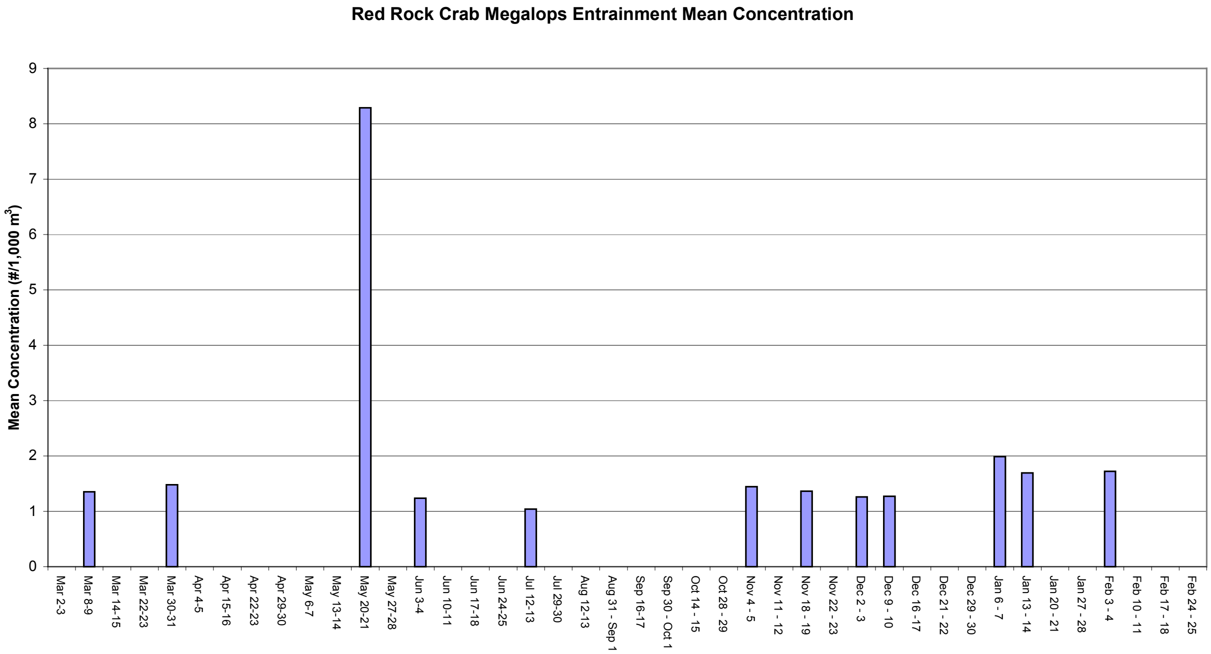
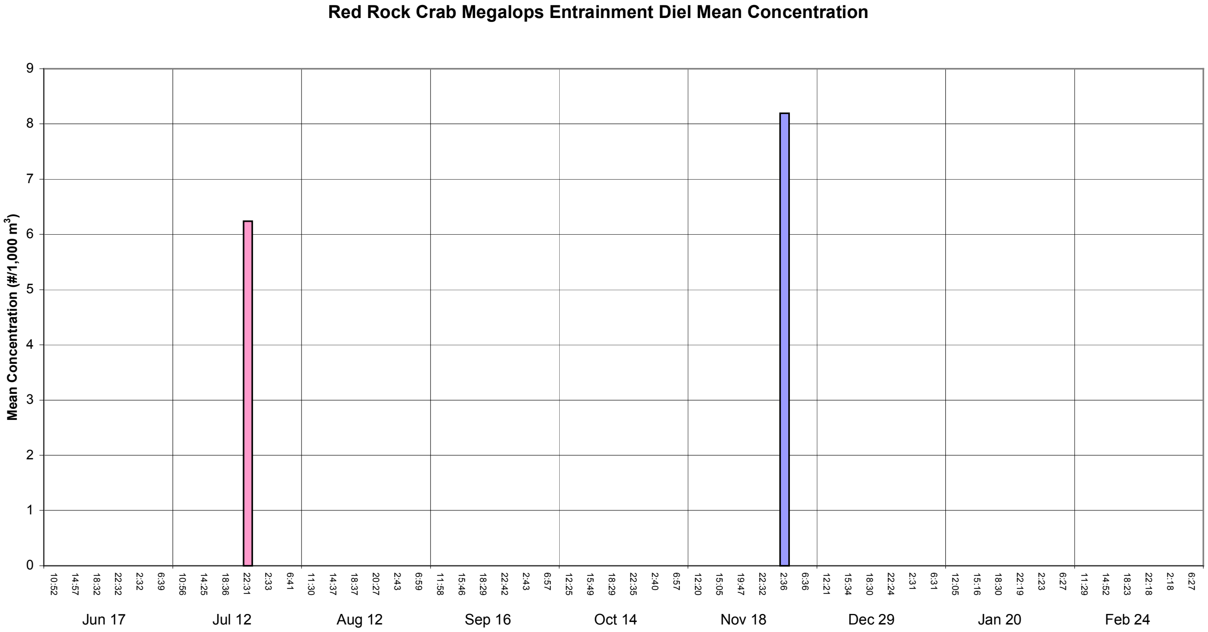


Figure 4-51. Mean survey concentrations (#/1,000 m^3) of red rock crab megalops at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

The diel distributions were plotted for concentrations of red rock crab megalops. We analyzed only the entrainment surveys that coincided with source water surveys from June 1999 through February 2000. They were collected only at night in July and November 1999 during one cycle (2231 and 0236 PST, respectively) (Figure 4-52).



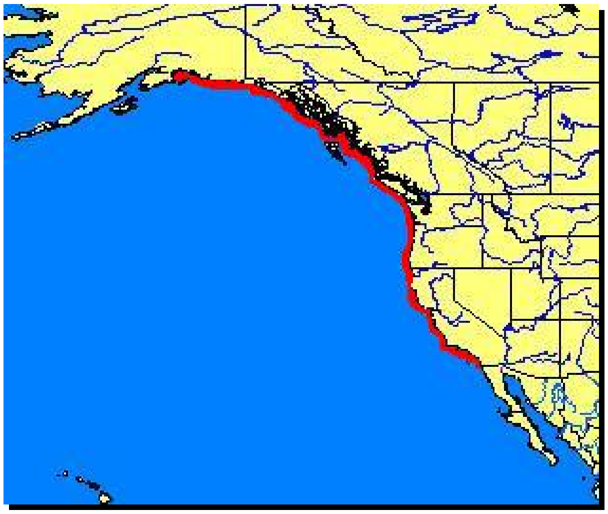
Note: These entrainment surveys were conducted at the same time as the source water surveys. Data are preliminary.

Figure 4-52. Concentrations (#/1,000 m^3) of red rock rock megalops at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Red rock crab megalops were not collected in any source water surveys from June 1999 through February 2000. It is important to note that the source water collections did not start until June 16, 1999 after the peak concentration occurred at the new combined-cycle units intake. Ocean and Harbor Mouth stations were not added to the sampling design until September 1999.

4.17 Slender Rock Crab *Cancer gracilis*

Cancer gracilis Photographer: MaGaw



Distribution Map for Slender Crab

***Range**:* From Prince William Sound, Alaska to Bahía Playa Maria, Mexico.

Life History: Size: males to 115 mm (4.5 in.), females to 87 mm (3.4 in.); age at maturity: approximately 10 months of age (post-settlement), about 60 mm (2.4 in.); fecundity: spawns once a season, 143,000 to one million eggs; life span: approximately 4 years.

Habitat: Sandy and muddy bottoms of intertidal areas to 174 m (571 ft), kelp and eelgrass beds, seasonally in bays and sloughs.

The slender crab, occasionally called graceful crab, are found from Prince William Sound, Alaska to Bahía Playa Maria, Mexico (Jensen, 1995). They inhabit the sandy and muddy bottoms of intertidal areas and are found subtidally, often in kelp beds to depths of 174 m (571 ft) and in eelgrass beds (Garth and Abbott, 1980). Slender crab do not osmoregulate and therefore cannot tolerate low salinity brackish environments. They are usually not found in estuaries, but may be found seasonally in bays and sloughs (Jensen, 1995).

Slender crab are often misidentified as dungeness crab, but are much smaller in size. Their carapace width measures up to 115 mm (4.5 in.) in males and up to 87 mm (3.4 in.) in females (Jensen, 1995). Their white-tipped claws lack the serrations belonging to dungeness crab and their purple walking legs are slender.

In Monterey Bay, spawning of slender crab have been reported to occur in the spring and fall (Graham, 1989). In Elkhorn Slough, mating is common in November and ovigerous females are found in the slough during July and August (Garth and Abbott, 1980). Females produce one batch per year, although in a laboratory setting, some females produced a small second batch. The number of eggs extruded per female can range from 143,000 to one million. Females are able to spawn for at least two, and possibly three seasons, over their lifetime (Orensanz and Gallucci, 1988).

After hatching, slender crab exist in a pre-zoeal stage for a very short time before molting to first stage zoeae. Slender crab progress through five zoeal stages to a megalops stage in an average of 48.9 days at 17º C; each stage lasting approximately one week (Alley, 1975). All larval stages are planktonic and the crab larvae may become widely distributed. In Monterey Bay, concentrations of first stage zoeae have been found from 6 to 11 km (3.7 to 6.8 miles) offshore during the spring and late summer (Graham, 1989). Other larval stages, including megalopae, are found distributed offshore at all times of the year. It is estimated that slender crab mature at a size of about 60 mm (2.4 in.) carapace width and at approximately 10 months of age (post-settlement) (Orensanz and Gallucci, 1988). Slender crab molt approximately 11 to 12 times and live for about 4 years.

In Monterey Bay, young slender crab are an important food source for the starry flounder *Platichthys stellatus* (Garth and Abbott, 1980). Slender crab feed on barnacles and bivalves, sometimes causing problems for the commercial oyster fishery. Some adults are occasionally taken in the sportfishery.

4.17.1 Slender Rock Crab Results (7.1 percent)

Slender rock crab comprised 7.1 percent of the total number of entrained *Cancer* spp. megalops (Figure 4-1). They were collected in the March 14, 1999 survey and again in November 1999 through mid-February 2000 surveys (Figure 4-53). Highest concentrations occurred on January 20, 2000 and February 3, 2000 (4.0/1,000 m^3 and 3.2/1,000 m^3, respectively). For all remaining surveys concentrations were at or below 2.0/1,000 m^3.

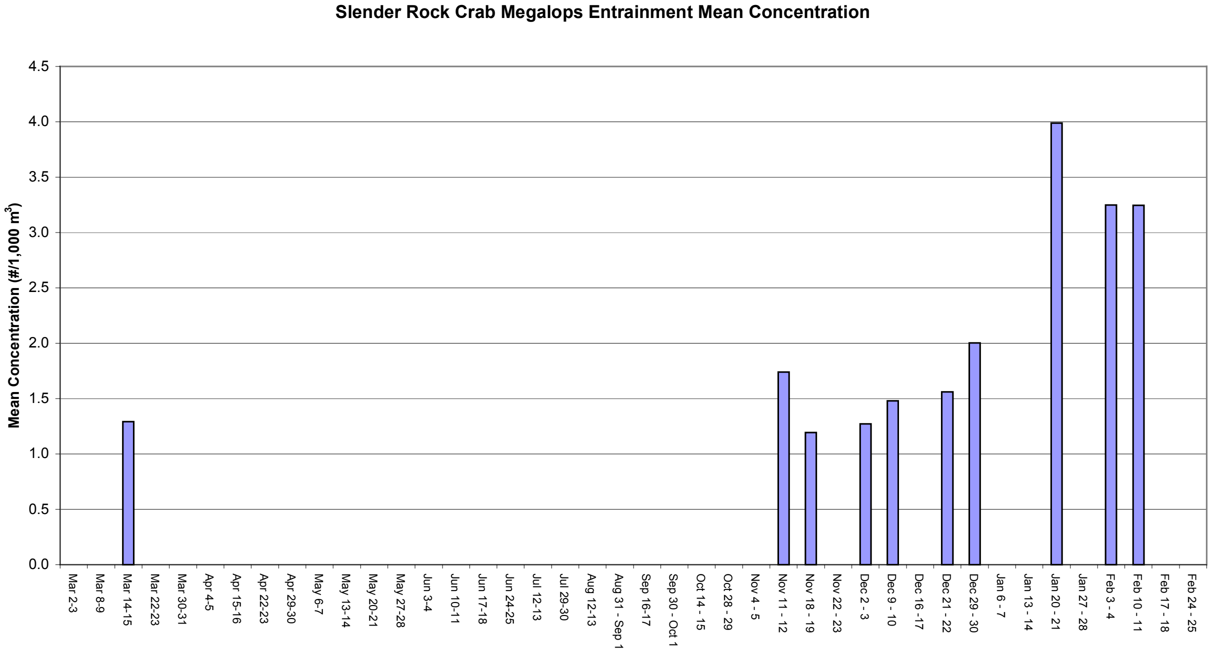
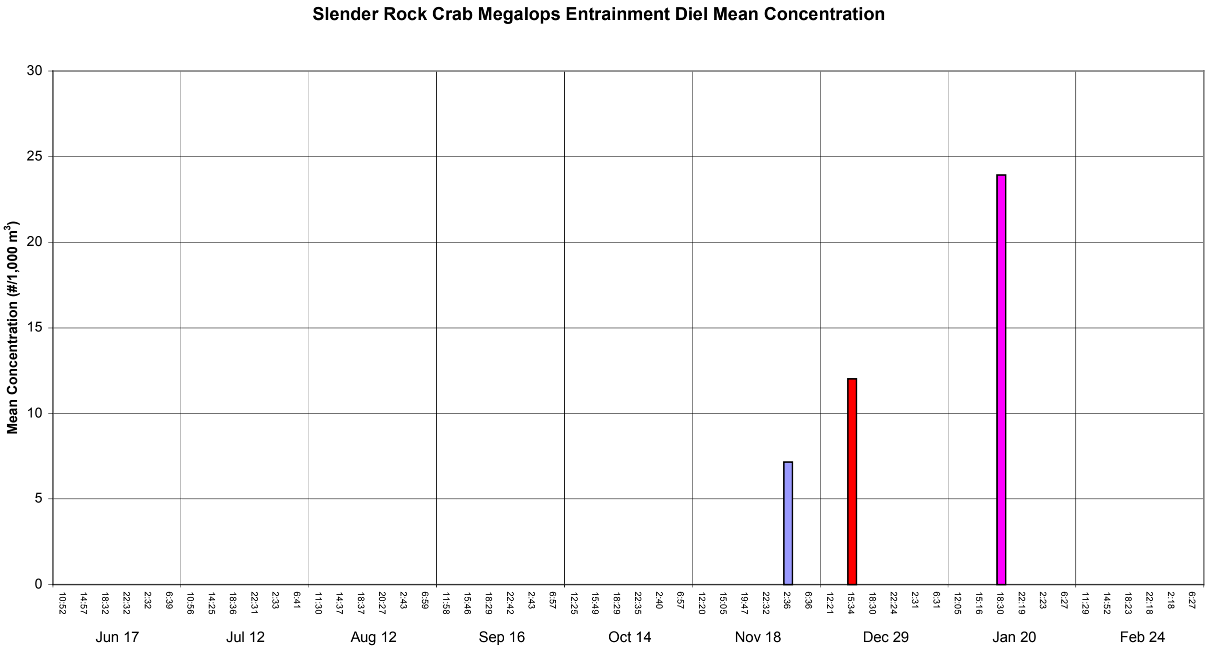


Figure 4-53. Mean survey concentrations (#/1,000 m^3) of slender rock crab megalops at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

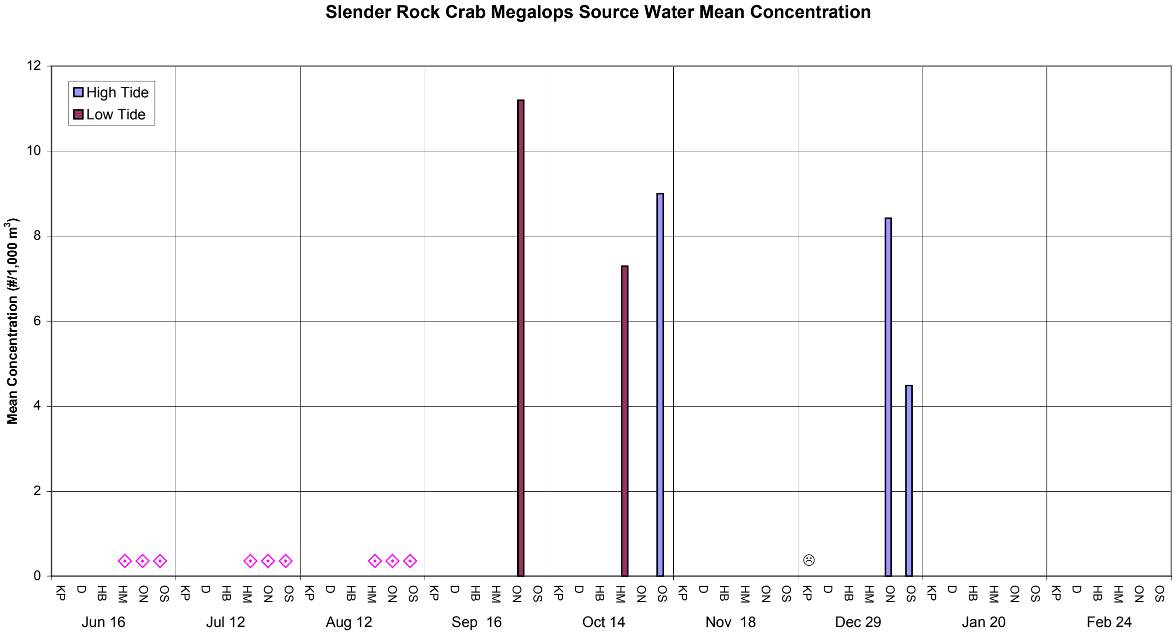
The diel distributions were plotted for concentrations of slender rock crab megalops. We analyzed only the entrainment surveys that coincided with source water surveys from June 1999 through February 2000. They were collected in only one cycle per survey (Figure 4-54) in November (1236 hours PST), December (1534 hours PST) and January 2000 (1830 hours PST).



Note: These entrainment surveys were conducted at the same time as the source water surveys. Data are preliminary.

Figure 4-54. Concentrations (#/1,000 m^3) of slender rock rock megalops at the new combined-cycle units intake separated by sample collection time (PST): June 1999 through February 2000.

Slender rock crab megalops were predominately collected at the Ocean North and Ocean South stations in September, October, and December 1999 (Figure 4-55). They were collected at the Harbor Mouth Station only on October 14, 1999 during low tide. Peak concentration (11.2/1,000 m^3) occurred during a low tide at the Ocean North Station on September 16, 1999.



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocean North; OS: Ocean South

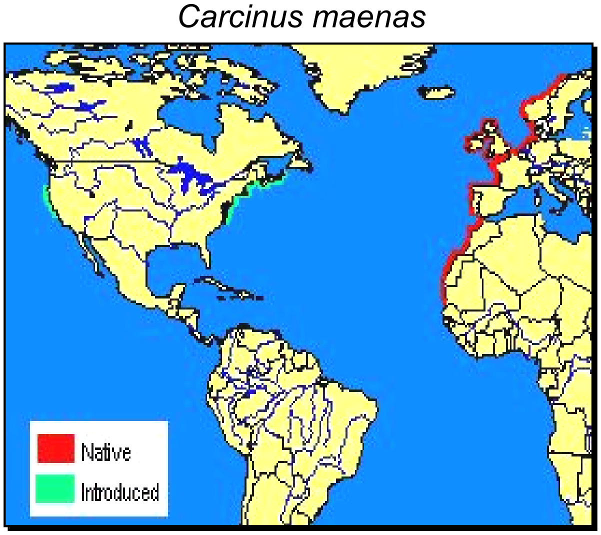
◇ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-55. Source water concentrations (#/1,000 m^3) of slender rock crab megalops at six stations near Moss Landing Power Plant: June 1999 through February 2000.

4.18 European Green Crab *Carcinus maenas*

Photographer: McGaw



Distribution Map for Green Crab*

*Also introduced to South Africa and Australia; distribution unknown

Range: Native: along the Atlantic Coast of Europe and North Africa from Norway to Mauritania; introduced to South Africa, Australia and both coasts of North America.

Life History: Size: males to 92 mm (3.6 in.) but rarely exceed 80 mm (3.1 in.); Fecundity: may spawn twice in a season, 185,000 eggs; Age at maturity: one to three years; Life span: to five years.

Habitat: A variety of protected and semi-protected marine environments, including rocky shores, cobble beaches, sand/mud flats, and tidal marshes; intertidally to depths of 10 m (33 ft.)

Fishery: No commercial or recreational fishery in U.S.

The European green crab *Carcinus maenas* is an environmentally tolerant species that has become widely distributed outside of its native range following unintentional introductions. The species is much maligned outside of its native range because of its voracious feeding habits. The green crab is a decapod crustacean belonging to the Infraorder Brachyura and Family Portunidae. Its native range extends along the Atlantic Coast of Europe and North Africa from Norway to Mauritania (Grosholtz, 1996). Introduced populations occur in South Africa, Australia, and along both coasts of North America (WDFW, 1999). The species has been documented on the Atlantic Coast of North America since the 1817 and now occurs from Nova Scotia to Virginia (Grosholtz, 1996). It was not found along the Pacific Coast until 1989/1990 when an established population was discovered in San Francisco Bay. Green crab were reported in Bodega Bay by

1993 and can now be found in every major bay and estuary between Monterey Bay and Humboldt Bay (Grosholtz, 1996). They have been reported to occur as far north as Willapa Bay, Washington and as far south as Morro Bay, California. The Willapa Bay population apparently did not persist (Jensen, 1995). Green crab occur in a variety of protected and semi-protected marine environments including rocky shores, cobble beaches, sand/mud flats, and tidal marshes (WDFW, 1999; Grosholtz, 1996; Cohen and Carlton, 1995). They are most often found in the intertidal and shallow subtidal regions of estuaries, typically in depths of less than 6 m (20 ft) (Jensen, 1995). They have been collected to depths of 10 m (33 ft) in San Francisco Bay (Cohen and Carlton, 1995).

One of the reasons for the success of the green crab is tolerance of a wide range of environmental conditions. Adult green crab are euryhaline and tolerate salinities from 4 to 52 ppt (Cohen and Carlton, 1995). The species is also eurythermal and lives in water temperatures ranging from 5° to 30° C (41° to 86° F) but are reported to tolerate temperatures to 0° C (32° F) (WDFW, 1999). The species also achieves reproductive success under a wide range of environmental conditions. Successful embryonic development can occur at temperatures between 11° and 25° C (52° to 77° F) (WDFW, 1999). Survival of eggs and larvae is high in salinities ranging from 26 to 39 ppt, however, larval development is inhibited in salinities of less than 13 ppt (WDFW, 1999). Because of the species' wide environmental tolerances it has been suggested that it may eventually range along the Pacific Coast from Alaska to Baja California (Cohen and Carlton, 1995).

The dorsal surface of the green crab carapace is smooth but somewhat irregular. Five anterolateral teeth line the anterior margin of the carapace on each side of the body. The teeth are oriented forward and are relatively acute. The last pair of walking legs, although not highly modified for swimming as in many other Portunid crabs, are slightly flattened (Jensen, 1995). Green crab are often multicolored dorsally and range from a dark mottled greenish to orange (Jensen, 1995). Yellow patches are often present on the dorsal surface. Coloration varies individually and with the length of time since the last molt (WDFW, 1999). A recently molted individual is typically dark mottled green in coloration and gradually turns to orange and then red as the intermolt period progresses. The ventral coloration is similarly variable. Green crab can reach a size of 92 mm (3.6 in.) but rarely exceed 80 mm (3.1 in.) (Jensen, 1995). Males grow faster and attain a larger size than females. Individuals typically live for 3 to 5 years in California (Grosholtz, 1996).

Mating in green crabs occurs immediately following the molt of a female. Much of the reproductive information available on the species has been collected in its native range. The timing of mating and settlement appears to vary geographically. In the North Sea, molting in females and subsequent mating occurs between April and November, but is most common from June to October (WDFW, 1999). Along the central coast of Maine mating occurs from July through October (WDFW, 1999). Smaller females may molt and mate early in the season and then again in the fall (WDFW, 1999). Males molt in the Baltic Sea between May and June; along the central coast of Maine, mature males have completed molting by July (WDFW, 1999). Eggs are usually extruded in the spring, although ovigerous females can be found from mid-winter to early summer (WDFW, 1999). Adult green crabs, particularly ovigerous females, are reported to migrate to deeper water during winter months (WDFW, 1999). It is thought that these females may move to deeper water to reduce variability in environmental factors such as salinity and temperature (WDFW, 1999). Female green crab can produce up to 185,000 eggs at a time under favorable conditions (Cohen and Carlton, 1995). Larvae are pelagic and aggregate in the upper layers of the water column at night during ebb tide. This behavior is thought to facilitate dispersal of the larvae into offshore waters where growth and development occur. Estimates of the period of time larvae spend in offshore waters vary from 2 weeks to as long as 2 months (at 15° C [59° F]) (WDFW, 1999; Grosholtz, 1996). After larvae molt to megalopae they again aggregate in the surface waters at night and are carried inshore with the flood tide. They eventually molt to juveniles and settle out in the upper intertidal zone. Grosholtz (1996) states that green crab recruit during the spring and mature during the first year. Other sources suggest that juveniles settle out in late August and maturity occurs during the second or third year (WDFW, 1999).

Green crabs are highly successful predators and consume a wide variety of invertebrates. The species is fast-moving and highly dexterous compared to other decapod crustaceans. It exhibits learning capabilities when handling prey, thereby reducing handling time during foraging (WDFW, 1999). Green crabs have been documented preying on organisms from more than 158 genera in 104 families (Cohen et al., 1995). Analysis of stomach contents included plants and protists from 5 phyla, and animals from 14 phyla. Dominant prey species varied at different locations but included mussels, clams, snails, polychaetes, crabs, isopods, barnacles, and algae (Cohen et al., 1995). In their native range, green crabs prey heavily on mussels *Mytilus edulis*, dogwelks *Nucella lapillus*, and cockles *Cerastoderma edule* (WDFW, 1999). Green crab have been reported to greatly reduce the abundance of its invertebrate prey populations, including commercially important species (Grosholtz, 1996).

There is great concern over the expansion of the green crab along the Pacific Coast of North America. Green crab predation on quahogs *Mercenaria mercenaria* is thought to have been a factor in the collapse of soft-shell clam fisheries along the Atlantic seaboard in the 1950's (WDFW, 1999). The species has also become problematic for the east coast hard shell clam *Mya arenaria* fishery (Grosholtz, 1996). In California, significant reductions in populations of the small clams *Nutricula* spp. and *Transennella* spp., the cumacean *Cumella vulgaris*, and the amphipod *Corophium* spp. have been attributed to green crabs (Grosholz, 1996; Grosholz and Ruiz, 1995). The species has also been documented preying on other crab species up to its own size. These include young Dungeness crab *Cancer magister* and the yellow shore crab *Hemigrapsus oregonensis*. Green crabs are voracious predators of young oysters *Crassostrea gigas* and frequently recruit into oyster culture bags (Grosholz, 1996). They are also a known intermediate host of an acanthocephalan worm *Profilcollis botulus* which has been known to cause heavy mortalities in seabirds (WDFW, 1999).

There is a commercial fishery for green crabs in Europe where they are used for both food and bait, however, because of their small size, no commercial harvest or marketing of the species has occurred in the United States. The most likely avenue of its introduction into San Francisco Bay is from larvae and juveniles contained in the ballast water of large ships. Green crabs are also known to occur in discarded packing material (algae) used for seafood products shipped from the New England coast. The species expansion up and down the coast may be the result of natural dispersal of larvae but could also be from ballast water or seafood packing material.

4.18.1 European Green Crab *Carcinus maenas* Results

European green crab megalops (3 individuals) were collected in only two (April 15 and April 22, 1999) entrainment surveys from the new combined-cycle units intake (Figure 4-56). Concentrations were 2.8/1,000 m^3 on April 15, 1999 and 1.2/1,000 m^3 on April 22, 1999.

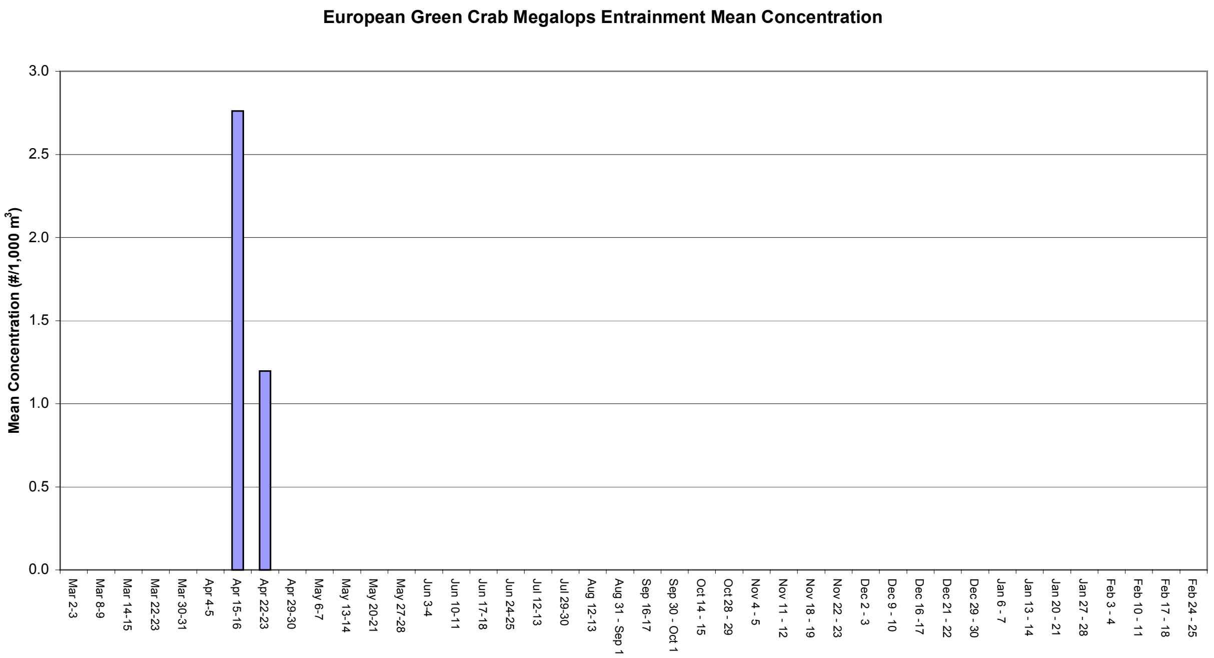
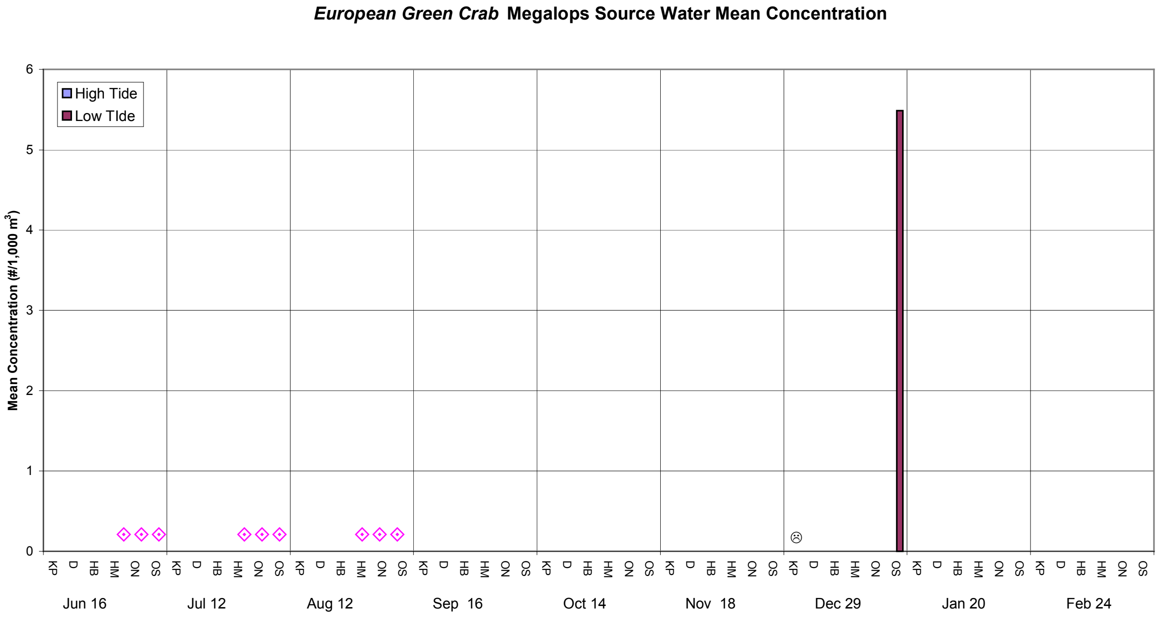


Figure 4-56. Mean survey concentrations (#/1,000 m^3) of European green crab megalops at the Moss Landing Power Plant new combined-cycle units intake: March 1999 through February 2000.

One European green crab megalop (concentration = 5.5/1,000 m3) was collected on December 29, 1999 at low tide from the Ocean South Station (Figure 4-57).



Key—KP: Kirby Park; D: Dairies; HB: Harbor Bridge; HM: Harbor Mouth; ON: Ocen North; OS: Ocean South

◇ Stations not included in study design until September.

☹ Samples voided due to improper preservation.

Figure 4-57. Source water concentrations (#/1,000 m^3) of European green crab megalops at six stations near Moss Landing Power Plant: June 1999 through February 2000.

5.0 IMPINGEMENT EFFECTS

The use of raw water in power plant cooling water systems (CWS) requires that objects in the water larger than the diameter of the condenser tubes be screened to avoid plugging the condensers. Most CWS intakes employ 3/8 in. (0.953 cm) mesh traveling screens that rotate out of the water to clear debris and organisms from the mesh. Cooling water that flows through the traveling screens can impinge weakly mobile organisms against the screens or entangled them in screened debris. These organisms are typically juvenile and adult fishes and macroinvertebrates. The location of the intake and traveling screens, the approach velocities, and the quantity of debris in the water are all factors that can affect impingement rates. Impingement studies were previously conducted at MLPP in 1979 – 1980, and the results were presented in the Moss Landing Power Plant Cooling Water Intake Structures 316(b) Demonstration (PG&E, 1983).

Most species of fish have the swimming capability to avoid impingement. Divers, swimming in front of the intake at the Diablo Canyon Power Plant, have documented young-of-the-year rockfish *Sebastes* spp., blackeye goby *Coryphopterus nicholsi*, and other small fishes swimming against the current just in front of the bar racks (Tenera, Inc., 1998). Other observations, recorded on video tape, showed a 15 cm (5.91 in.) painted greenling *Oxylebius pictus* swimming off of the traveling screen after apparently resting there (Tenera, Inc., 1998). However, it has been demonstrated that when there are large amounts of detritus (plant material) in the intake area, organisms strong enough to avoid the intake may become trapped in the detritus and become susceptible to impingement (PG&E, 1982).

The common size screen mesh of 3/8 in. (0.953 cm) is designed both to prevent condenser tube from plugging and to minimize the approach and through-screen velocities for fish protection. As the mesh size is increased more larval and juvenile fish will enter the power plant's cooling water system (be entrained) and subjected to mechanical, chemical, and thermal stresses. A reduction in mesh size of traveling screens will increase the rate of impingement and the stress of through-screen velocities. Entanglement in debris also increases with through-screen-velocities. If there is no fish return system, these impingement effects decrease directly with reductions in through-screen-velocities.

Consistent with the final study plan, impingement studies are not being conducted as a part of this 316(b) demonstration. Several of the modifications that will be made to the Units 1 through 5 intake structure as part of the modernization project (Section 2.1) are expected to reduce the quantity of debris and the number of organisms impinged on the traveling screens at that location and are discussed below. It is important to note that the data from the prior impingement study showed the overall rate of impingement (standardized for differences in cooling water flow) was higher at the Units 1 through 5 intake than at Units 6 and 7 intake. This was true for both fishes and macroinvertebrates (by a factor of 1.6 for fishes and 3.3 for macroinvertebrates) (PG&E, 1983).

The cooling water volume pumped through the Units 1 through 5 intake structure will be reduced from 381,000 gpm (1,441 m^3/min) to 250,000 gpm (946 m^3/min) for the new combined-cycle units. As a result of the lower flows, approach velocities will decrease from 0.9 feet per second (fps; 0.27 meters per second [mps]) to 0.5 fps (0.15 mps). The new traveling screens will be inclined at an approximate angle of 73° from horizontal thus providing more surface screen area that will result in lower through-screen velocities. During screen rotation of the vertical traveling screens, debris has a tendency to fall back into the water at the air/water interface and create a large mass. These new angled screens will be more effective at removing debris than the conventional vertical traveling screens. The existing intake tunnel is approximately 350 ft (106.7 m) long (measured from the bar racks to the traveling screens). The new combined cycle (CC) forebay intake design places the traveling screens approximately 10 feet (3.1 m) behind the bar racks. The shortening of the tunnel may help to reduce impingement of schooling fishes that can become trapped in the tunnel and subsequently impinged.

Data presented in this section are from impingement studies conducted at the Moss Landing Power Plant in 1979 – 1980 as part of the first 316(b) Demonstration program (PG&E, 1983). Data reported in PG&E (1983) were presented as numbers of organisms caught during each impingement collection. We have obtained the actual cooling water volumes for Units 1 through 5 and Units 6 and 7 for the period of the impingement study and have calculated densities of the most abundantly impinged fishes and *Cancer* spp. crabs.

The 1983 evaluation found that the power plant was employing BTA intake technology. The evaluation indicated that the existing cooling water intake system impinges small numbers of adult fishes and invertebrates on the intake screens.

5.1 Impingement Study

The impingement study (PG&E, 1983) was designed to quantify the composition and abundance of impinged organisms at both Units 1 through 5 and Units 6 and 7 of the MLPP. Lengths and weights of all fishes and selected macroinvertebrates impinged in 24-hour periods were recorded. Seasonal and diel (day and night) patterns of impingement were determined graphically.

5.1.1 Methods

Impinged fishes and macroinvertebrates were collected from weekly samples at the intakes of both Units 1 through 5 and Units 6 and 7. The impingement study began on January 20, 1979 and continued through March 18, 1980. Samples were taken over a 24-hour period that was divided into either 3- or 6- hour cycles. This cycle-breakdown of sample collection allowed for the determination of the diel distribution of the impinged organisms.

Before each sampling period all the traveling screens were rotated and rinsed to remove previously impinged organisms and debris. The screens remained stationary for 2.75 hours and then were rotated for 15 minutes while impinged organisms were rinsed into a collection basket lined with ¼-inch (0.635 cm) steel mesh. This procedure was repeated for the entire 24-hour sampling period.

The impinged organisms were removed from the detritus. Fishes and macroinvertebrates were identified to species, counted, and measured. The fork length (tip of snout to fork in tail) of the fishes was measured for up to 50 individuals of each species, carapace widths measured for Cancer spp. and the mantle length was recorded for squids and octopus in every 24-hour collection.

Gonads of the most commonly impinged fish were periodically examined to assess spawning condition. Gonads were dissected from the fish and classified as undeveloped, developing, mature, or spent.

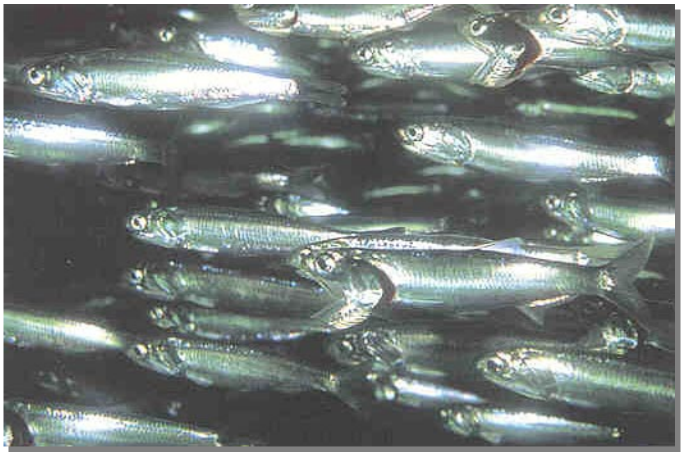
All samples were subjected to a Quality Control program that called for resorting sample debris and reidentification of the collected organisms. Sampling efficiency was also tested in various experiments. Marked dead fish were released directly in front of the intakes and the number of recovered fishes was recorded. Eighty-seven percent of the dead fish released into the Units 1 through 5 intake were recovered in this test of sampling efficiency but only 35 percent were recovered from Units 6 and 7. The low recovery rate for Units 6 and 7 was attributed to a traveling screen design that was built to remove jellyfish, kelp, and algae. This system consists of L-shaped brackets or cylindrical projections attached to the traveling screens. These brackets interfered with the effectiveness of the spraywash system and some of the impinged material was carried over and bypassed the secondary sluiceway. It was observed that this “carry-over” occurred when there was insufficient water pressure. The differential collection efficiencies between the two intakes were taken into consideration when impingement characteristics were compared.

5.2 Life Histories of Abundantly Impinged Fishes

5.2.1 Fishes

Northern anchovy *Engraulis mordax* was the most abundant fish species collected from both intakes and constituted 61 percent of all fishes impinged. Shiner perch *Cymatogaster aggregata* ranked second in abundance at 9 percent, followed by topsmelt *Atherinops affinis* (9 percent) and Pacific herring *Clupea pallasi* (4 percent). These four species accounted for 83 percent of all fishes impinged during the entire study. Life histories for these species, except Pacific herring (discussed previously in Section 4.10), are presented below.

Northern Anchovy *Engraulis mordax*



Photographer: Mark Conlin

The northern anchovy *Engraulis mordax* is a clupeoid fish (anchovy, sardine, and herring) belonging to the family Engraulididae (the anchovies). Engraulididae contains 139 species of anchovies that occur throughout the world (Moyle and Cech, 1988). Members of the family can be distinguished from other clupeids by their overhanging snout and long upper jaw (Moyle and Cech, 1988). Northern anchovy, one of the most prolific fishes in the coastal waters of the Pacific, contribute significantly to the economics of the world’s fisheries.

The northern anchovy population has been separated into three distinct sub-populations, based on morphological differences, and are represented geographically by the northern, central, and southern sub-populations (PFMC, 1990; Love, 1996). The northern sub-population is found from Vancouver Island, British Columbia to central California. The distribution of the central sub-population extends from central California to northern Baja California and the southern population is found along the southern coast of Baja. Considerable fluctuations in anchovy populations occur in response to cyclic variations in oceanographic conditions (Moyle and Cech, 1988).

Northern anchovy are a pelagic marine species that occurs from surface waters down to depths of 305 m (1,000 ft) (Love, 1996). They can be found in dense schools within bays and estuaries, and in ocean waters from just outside the surf zone to more than 300 miles offshore (Love, 1996). They are most common within 100 miles of land (Love, 1996). Anchovies make extensive seasonal movements up and down the coast, as well as offshore and inshore (Love, 1996). Their pattern of seasonal movement is moderately predictable, at best. Schools generally disperse and move toward the surface waters around sunset to feed. They re-form into larger, more consolidated schools later in the night (Love, 1996).

Northern anchovy are elongate fishes with blue or green backs and silver bellies. They have been reported to reach a size of 229 mm (9 in.) but rarely exceed 178 mm (7in.) (Miller and Lea, 1972; Love, 1996). Northern anchovy may live to 7 years, but most do not live past 5 years of age. There are geographic differences between the time when individuals become reproductively mature. While all anchovy are mature by the time they reach 4 years in age, some may mature within their first year in the southern parts of their range (Love, 1996).

Spawning occurs throughout the year (with peaks in December through May) in the southern end of the northern anchovy's range, but is seasonal in the northern locations. Near the Columbia River, off of the coast of Washington and Oregon, the fish spawn from mid-June through mid-August. Most spawning occurs within 150 miles from shore and typically takes place at night. Females are oviparous and can spawn 2 to 3 times a year, releasing from 2,700 to16,000 eggs per batch (Brewer, 1978). Love (1996) indicates that females can release from 2,700 to 16,000 eggs per batch, with annual fecundity as high as 130,000 eggs in southern California. The number of eggs produced varies geographically. Eggs are pelagic and are broadcast into the water column (Bolin, 1936; Wang, 1986). The eggs hatch in 2 to 4 days and larvae begin their pelagic phase at approximately 3 mm TL (Wang, 1986; Love, 1996). The larval phase lasts for approximately 70 days (Wang, 1986; Love, 1996). Larvae begin schooling at 11 to 12 mm (0.43 to 0.47 in.) and transform into juveniles at 35 to 40 mm (1.38 to 1.57 in.) (Hart, 1973). Survival of juveniles is thought to be greatest during calm ocean conditions (Love, 1996).

Northern anchovy are primary consumers and filter-feed on plankton. They feed on zooplankton such as krill, copepods, and arrow worms, and on phytoplankton, small fishes, and pelagic fish eggs (Love, 1996). Anchovy are undoubtedly one of the major forage fishes within their range. Marine mammals, sea birds, fishes, and invertebrates all prey on anchovy at some stage of their life.

Northern anchovy in the central sub-population are harvested commercially in Mexico and California for reduction, human consumption, live bait, dead bait, and other non-reduction commercial uses (PFMC, 1998). Landings of northern anchovy in California between 1916 and 1997 varied from a low of 72 metric tons (MT) in 1926 to a high of 143,799 MT in 1975

(PFMC, 1998). This historical variation in landings generally reflects changes in both anchovy populations and the interest of fisherman to fish for them. The most recent stock assessment for northern anchovy estimated spawning biomass at 388,000 MT during the middle of February 1995 (Jacobson et al., 1995). Although no more recent stock assessments have been made, a qualitative analysis of the available data indicates that this remains the best estimate of current spawning biomass (Jacobson et al., 1997).

Shiner perch *Cymatogaster aggregata*

Shiner perch *Cymatogaster aggregata* belong to the small (23 species) family Embiotocidae which are found abundantly in sub-tropical and temperate waters along the Pacific coast of North America and Asia (Moyle and Cech, 1988). Shiner perch range from San Quintin Bay, Baja California to Port Wrangell, Alaska (Miller and Lea, 1972). They are abundant from British Columbia south (Love, 1996). Shiner perch and striped surfperch *Embiotoca lateralis* are the two most widely distributed embiotocid species (Odenweller, 1975).

Shiner perch inhabit a wide variety of habitats including estuaries and quiet bays, eelgrass beds *Zostera marina*, and open coast areas around kelp beds. They are also frequently found in the vicinity of piers, jetties, and oil platforms. Shiner perch occur commonly in schools and aggregations from the intertidal zone down to depths 61 m (200 ft) (Love, 1996). They are most often found in depths of less than 15 m (50 ft) but have been collected as deep as 210 m (690 ft) (Love, 1996). They are euryhaline and can also be found in lower salinity areas of coastal streams and even occasionally in freshwater (Fierstine et al., 1973; Love, 1996). They are also reported to be eurythermal and live in water ranging from 4° C to 21° C (39° F to 70° F) (Odenweller, 1975; Love, 1996).

Shiner perch are small fishes that are silvery in overall appearance but have black spots on their scales. The black spots form a background pattern of thin horizontal stripes along the sides of the fish (Humann, 1996; Love, 1996). There are several (usually 3) vertical yellow bars overlaid on the pattern along the mid-body (Humann, 1996; Love, 1996). There is often a dusky patch on the snout below the nostril (Humann, 1996; Love, 1996). Shiner perch reach a size of 178 mm (7in.) and may live for 8 years (Love, 1996). They become reproductively mature after 1 year (Love, 1996).

Spawning in shiner perch occurs during the spring and summer. Odenweller (1975) related the timing of spawning to the temperature and productivity of the environment. In the southern portions of its range spawning begins in April-May, while in British Columbia it begins in June-August. Females are ovoviviparous and young are born during the winter months. Females store sperm for a period of time before embryo development begins. Thirty-six embryos may develop in a single female (Love, 1996). Because of their greatly enlarged and highly vascularized dorsal, pelvic, and anal fins, embryos are able to obtain nutrients from the mother (and develop) in uterus-like sacs within the ovary. When born they may be greater than 3 cm in length (Moyle and Cech, 1988).

Shiner perch feed primarily on planktonic organisms such as copepods, amphipods, arrow worms and fish eggs (Love, 1996). When zooplankton abundance is low they will feed heavily on benthic organisms such as pelecypods, gastropods, polychaetes, tunicates, and fish eggs (Odenweller, 1975).

Shiner perch are preyed upon by a wide variety of marine mammals, birds, and fishes. Oxman (1995) determined that shiner perch composed 2.87 percent of the prey items consumed by harbor seals *Phoca vitulina* in the Moss Landing/Elkhorm Slough area. California sea lions *Zalophus californianus* are also reported to feed on shiner perch (Love, 1996). They have a variety of avian predators including: great blue herons *Ardea herodias*, western gulls *Larus occidentalis*, bald eagles *Haliaeetus leucocephalus*, least terns *Sterna antillarum* and Brandt's *Phalacrocorax penicillatus* and double-crested cormorants *Phalacrocorax auritus* (Love, 1996). Shiner perch are also consumed by a number of piscivorous fishes. California halibut *Paralichthys californicus*, kelp bass *Paralabrax clathratus*, and barred sand bass *Paralabrax nebulifer* are among their many piscine predators (Love, 1996). Although small landings are made, shiner perch have little commercial value. They are caught by recreational anglers in bays and from piers and are considered a good baitfish for a number of gamefish.

Topsmelt *Atherinops affinis*

Topsmelt, along with jacksmelt and grunion, belong to the family Atherinidae (silversides). These schooling fish are found from the Gulf of California to Vancouver Island, British Columbia (Miller and Lea, 1972), occasionally extending as far north as Queen Charlotte Islands, British Columbia (Humann, 1996). They are most commonly found from Tillamook Bay, Oregon southward and are very abundant in California waters (Love, 1996).

Topsmelt usually aggregate in shallow waters and tend to school near the surface, although they may be seen as deep as 9 m (30 ft)(Love, 1996). Topsmelt are often the most abundant fishes in estuaries. They are also found in kelp canopies, along sandy beaches, and at times, offshore. The San Francisco topsmelt (*Atherinops affinis affinis*), is distinctive because it is the only one of the three subspecies in this range to be found in the Sacramento-San Joaquin estuary. Topsmelt commonly live in the salt ponds near the southern end of San Francisco Bay, withstanding salinity concentrations three times greater than that of ocean water. Topsmelt are tolerant to a wide range of salinities, as they also live in fresh and brackish water (Carpelan, 1955).

Topsmelt are silvery green along their backs with a silver stripe midline along their side. They can reach up to 368 mm (14.5 in.) (Love, 1996) and may live six to nine years (Wang, 1996). These fishes mature between two and three years of age (Love, 1996) although Carpelan (1955) reported that the topsmelt of the salt ponds near Alviso spawned when they were one year old.

Topsmelt spawn along the Pacific coast and in estuaries. In San Francisco Bay, spawning generally occurs between April and October, with a peak in May and June (Wang, 1996). Females probably spawn more than once (Wang, 1986) and produce between 200 to 1,000 eggs per season (Love, 1996). Spawning takes place primarily at night. Topsmelt eggs form large clusters as they become entangled in the variety of marine plants used as spawning substrate. Topsmelt larvae of the estuaries tend to swim in schools near the surface of shallow and open water, whereas pelagic larvae along the coast remain in the top few inches of the kelp canopies.

Topsmelt feed on plankton, algae, crustaceans, detritus, amphipods, and insect larvae. This species is targeted by California sealions, harbor seals, least terns, and Brandt's and double-crested cormorants. Topsmelt are also used as food and bait (Love, 1996).

Bocaccio *Sebastes paucispinis*

Bocaccio are one of the most wide-ranging and commercially important rockfish species. They belong to the family Scorpaenidae that is composed rockfishes and scorpionfishes and is represented by more than 310 species worldwide (Moyle and Cech, 1988). Bocaccio are one of the more than 60 species in the genus *Sebastes* that occur off the Pacific Coast of North America (Moyle and Cech, 1988). The range of bocaccio extends from Stepovak Bay, Alaskan Peninsula to Pt. Blanca, Baja California (Miller and Lea, 1972; Love, 1996). They are most abundant from British Columbia and southern Alaska to central Baja California (Love, 1996). Bocaccio often form large aggregations and tend to occur near the bottom. Though generally associated with hard benthic substrates, they may be found over mud and sand bottoms or high in the water column (Love, 1996). Bocaccio occur from the surface down to depths exceeding 457 m (1,500 ft). Adult bocaccio are generally found in deeper, offshore waters and are most common in depths from 46 m (150 ft) to 305 m (1,000 ft) (Love, 1996). Juveniles may be found in surface waters under drifting mats of kelp or around inshore reefs and kelp beds (Love, 1996). Huge aggregations of juvenile bocaccio invade shallow nearshore waters during certain years. Bocaccio gravitate into deeper water as they grow and are thought to move about extensively as adults. Tagged juveniles have been recaptured 60 and 80 miles from their release site (Love, 1986).

Bocaccio are an elongate, moderately compressed species of rockfish with a square to slightly indented tail. They are readily distinguished from other rockfish species of similar body shape by their coloration and large mouth, in which the maxillary extends beyond the rear margin of the eye orbit, while in chilipeppers *Sebastes goodei* and silvergray rockfish *Sebastes brevispinis* the maxillary only extends to the middle or rear of the orbit. The lower jaw of bocaccio projects upward, ending with a prominent symphyseal knob. Adults are a dark, rusty-brown to gray color dorsally, gradating to a silvery belly. There is scattered spotting on the back and sides of juveniles and most adults. In adults, the spotting is largely confined to areas above the prominent lateral line. Chilipeppers and silvergray rockfish do not have spotting. Melanistic (black) blotches are also present on a small proportion of the adult bocaccio population. The size, shape, location, and number of these blotches varies with affected individuals. Melanistic blotches occur on several other schooling, deepwater rockfish species.

Bocaccio are ovoviviparous or primitively viviparous with fertilization and embryonic development taking place within the body prior to larval extrusion (Phillips, 1964; Love, 1996). Fecundity varies proportionately with the size of the female. A 381 mm (15 in.) fish may produce 20,000 eggs per season while a 762 mm (30 in.) fish can produce many as 2.3 million eggs in a season (Phillips, 1964; Love, 1996). When embryonic development is complete a female extrudes her “eyed” larvae into the surrounding water, which activates them (Morris, 1956; Phillips, 1964). Larvae range from 3.7 mm (0.15 in.) to 5.4 mm (0.21 in.) in length at extrusion.

Spawning season varies somewhat with latitude. In southern California spawning peaks in January but may occur in during most other months of the year (October through July) (Love, 1996). In central and northern California spawning occurs from January to May and peaks in February (Love, 1996). Further north spawning takes place from January through March (Love, 1996). Larval bocaccio are pelagic planktivores and typically occur in the top 100 feet of the water column (Thomas and Bence, 1992). They are widely distributed over the continental shelf and have been collected in plankton nets as far as 300 miles offshore (Thomas and Bence, 1992; Love, 1996). When larvae reach a size of 38 to 64 mm (1.5 to 2.5 in.) they begin settle out of the water column and orient to bottom substrates (Thomas and Bence, 1992). Settlement generally occurs by late May or early June (Thomas and Bence, 1992).

Bocaccio are relatively large rockfishes at adulthood and grow rapidly compared to many of the deepwater rockfish species. Bocaccio grow to over 910 mm (36 in.) reaching a weight of 15 pounds (Thomas and Bence, 1992; Love, 1996). They live for at least 35 years and possibly as long as 40 (A. Andrews MLML pers. comm.). At 8 to 10 years of age a bocaccio is around 610 mm (24 in.) in length and may weigh 2.3 kg (5 lbs) (Thomas and Bence, 1992; Love, 1996). Females grow significantly faster than males and are larger when they mature (Phillips, 1964; Love, 1996). Females are also thought to have a longer lifespan (Love, 1996). Size at maturity varies geographically, with individuals in southern California maturing between 356 and 457 mm (14 to 18 in.) and individuals to the north maturing between 559 and 610 mm (22 to 24 in.) (Love, 1996).

The rapid growth of young bocaccio is fueled by their diet of small fishes. Other young rockfish *Sebastes* spp., surfperch (Family Embiotocidae), jack mackerel *Trachurus symmetricus*, and a variety of small inshore fishes compose the bulk of their diet by the end of their first year (Phillips, 1964). As bocaccio grow and move to deeper water they continue to prey primarily on fishes, however, they will also consume invertebrate species such as market squid *Loligo opalescens* and pelagic red crabs *Pleuroncodes planipes*. Small rockfishes *Sebastes* spp., sablefish *Anoplopoma fimbria*, northern anchovies *Engraulis mordax*, and lanternfish (Family Myctophidae) are among the fishes frequently consumed by adult bocaccio (Phillips, 1964; Love, 1996). Pinnipeds such as harbor seals *Phoca vitulina* and northern elephant seals *Mirounga angustirostris* are among the predators of bocaccio (Love, 1996). Juveniles also fall prey to a variety of seabirds.

Historically bocaccio have been a major component of commercial rockfish landings in California. In addition to being the dominant rockfish species in California's early longline fishery, it was the most abundant rockfish harvested in the otter trawl fishery from Morro Bay to Fort Bragg until the mid-1980s (Thomas and Bence, 1992). Bocaccio have also been a prominent species in set gillnet and hook and line rockfish fisheries. Since the mid-1980s chilipepper have replaced bocaccio as the dominant rockfish species in the trawl fishery (Thomas and Bence, 1992). Federal management of bocaccio began in 1982 and because of its continued decline in abundance an annual harvest guideline of 4 million pounds was established for the species in 1991 (Thomas and Bence, 1992). Biomass estimates for the species fell from 150 million pounds in 1978 to 20 million pounds in 1989 (Thomas and Bence, 1992). Landings of bocaccio have continued to decline in the 1990s and quotas have become increasingly restrictive. Declines in landings can be the result of a number of factors including the species' abundance, more restrictive quotas, and market forces.

Commercial bocaccio landings in California were first accurately estimated in 1978 when they averaged around 4 million pounds annually (Thomas and Bence, 1992). Accurate landing data for bocaccio are not available from 1981-1990 (in CDFG Landing Summary) because the majority of bocaccio were landed in a combined bocaccio/chilipepper market category (Figure 5-1 and Figure 5-2). From available CDFG data, landings of bocaccio peaked at over 10 million pounds by 1980 and then began a slow but steady decline until 1990 when landings were again about 4 million pounds (CDFG Landing Summary). Beginning in 1991, when a quota for the species was established, landings declined from over 2 million pounds (in 1991, 1992, and 1993) to less than 300,000 pounds in 1998 (Figure 5-3). The ex-vessel price for bocaccio since 1986 has averaged 39 cents a pound and ranged from a low of less than 33 cents in 1986 to a high of around 50 cents in 1998 (CDFG). Virtually all bocaccio are processed (filleted) and sold fresh as rock cod or red snapper fillets.

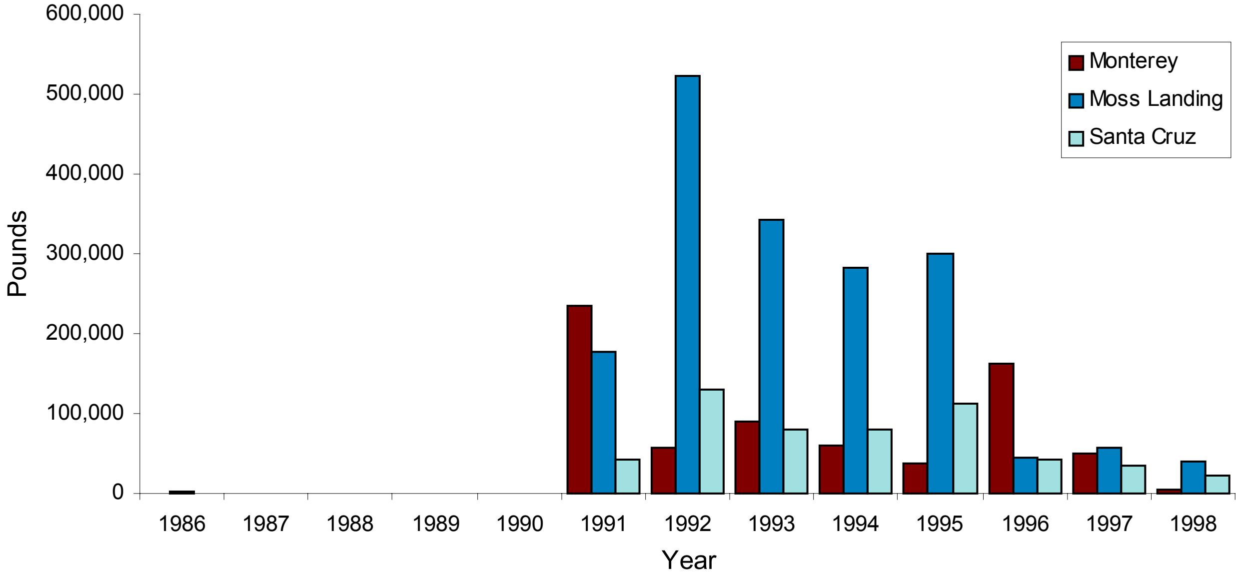
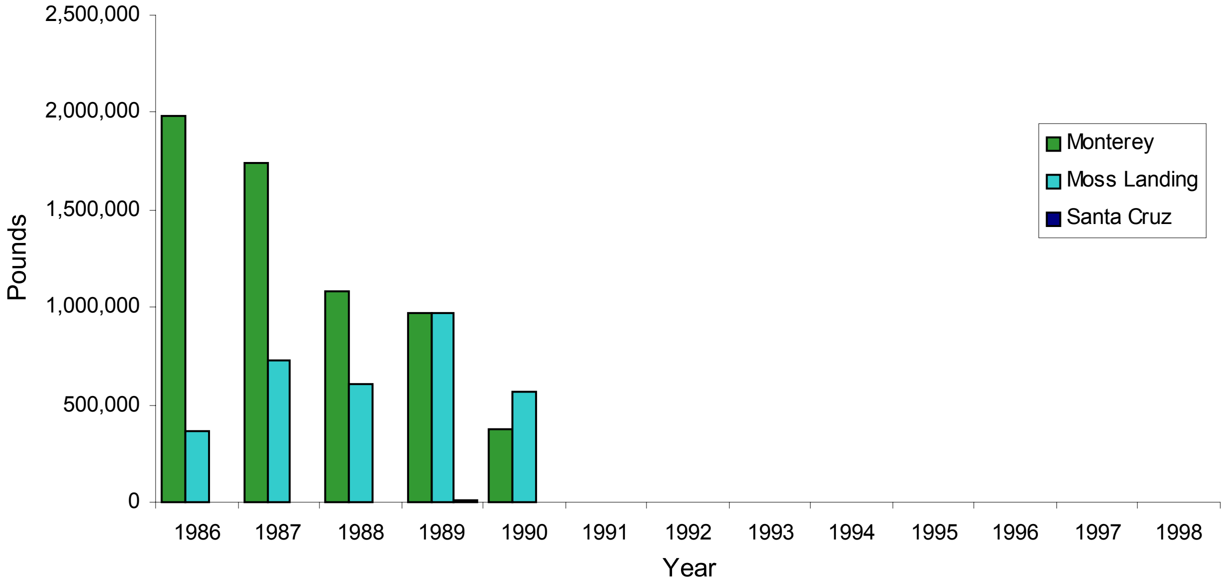
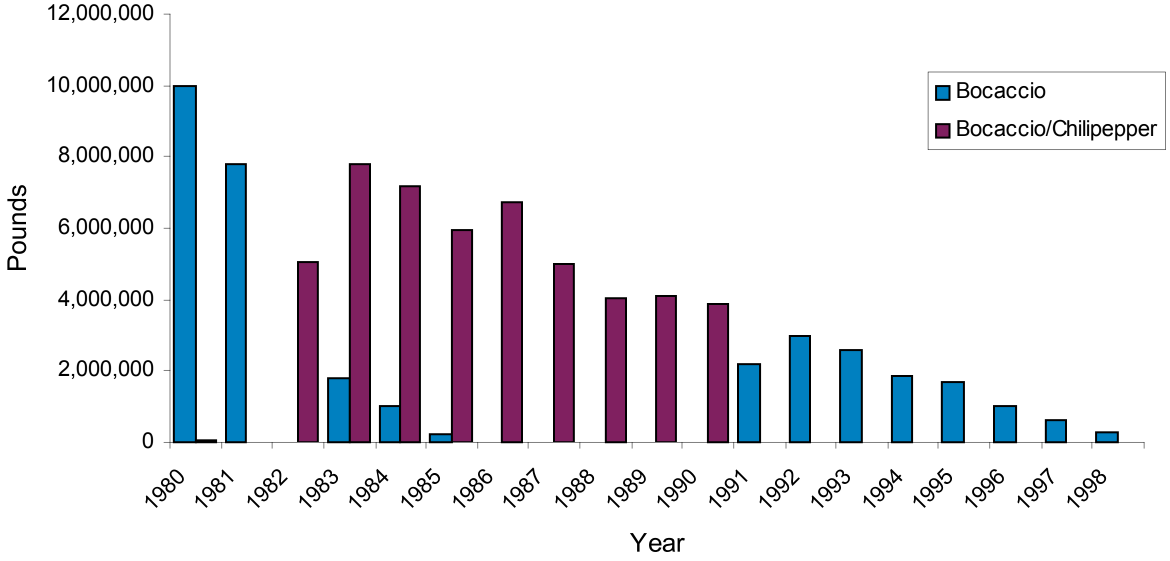


Figure 5-1. Bocaccio landings from Monterey Bay ports. Includes market category 253 (bocaccio).



Source: CDFG Landing Summaries 1986–1998.

Figure 5-2. Landings of combined market category for bocaccio/chilipepper. Includes market category 956 (bocaccio/chilipepper).



Source: CDFG Landing Summaries 1986–1998.

Figure 5-3. Bocaccio landings from California including the combined category for bocaccio and chilipepper.

Bocaccio are also an important species in recreational catches along the coast of California and Oregon (Love, 1996). A majority of party boat landings of the species occur from Mendocino County, northern California to southern California (Love, 1996). In southern California bocaccio may account for as much as 14 percent of the total recreational catch (Thomas and Bence, 1992; Love, 1996). They are generally caught in greater abundance in the southern California fishery than in the northern California fishery (Thomas and Bence, 1992; Love, 1996). Recreational catches of bocaccio by the party boat fleet are typically made in depths of 76 m (250 ft) to 229 m (750 ft) of water (Thomas and Bence, 1992). Since 1984 recreational landings of the species have followed the same trend as commercial landings (Thomas and Bence, 1992). Beginning in 1999 the recreational take of bocaccio was restricted to 3 fish per day.

Pacific herring *Clupea pallasi*

The life history of the Pacific herring is discussed in Section 4.10 of this report.

5.2.2 Macroinvertebrates

A majority (62 percent) of the total macroinvertebrates impinged by both MLPP intakes was collected from Units 1 through 5. *Cancer* spp. crabs constituted 37 percent of the total number of macroinvertebrates impinged at Units 1 through 5 and 9 percent at Units 6 and 7. *Crangon* spp. shrimps constituted 19 percent of the total number impinged at Units 1 through 5 and 31 percent at Units 6 and 7. The species composition of impinged organisms was generally similar between the two intakes.

Rock Crabs *Family Cancridae*

The life history of the rock crab is discussed in Section 4.11 of this 316(b) Demonstration Report.

Hairy Rock Crab *Cancer jordani*

The life history of the hairy rock crab is discussed in Section 4.12 of this 316(b) Demonstration Report.

Yellow Rock Crab *Cancer anthonyi*

The life history of the yellow rock crab is discussed in Section 4.13 of this 316(b) Demonstration Report.

Brown Rock Crab *Cancer antennarius*

The life history of the brown rock crab is discussed in Section 4.14 of this 316(b) Demonstration Report.

Dungeness Crab *Cancer magister*

The life history of the dungeness crab is discussed in Section 4.15 of this 316(b) Demonstration Report.

Red Rock Crab *Cancer productus*

The life history of the red rock crab is discussed in Section 4.16 of this 316(b) Demonstration Report.

Slender Rock Crab *Cancer gracilis*

The life history of the slender rock crab is discussed in Section 4.17 of this 316(b) Demonstration Report.

European Green Crab *Carcinus maenas*

The life history of the European green crab is discussed in Section 4.18 of this 316(b) Demonstration Report.

Oregon cancer crab *Cancer oregonensis*

The Oregon cancer crab ranges from St. George Island, Pribilof Islands, Alaska to Palos Verde, California, although they are uncommon south of Point Arena, California (Jensen, 1995). They are found in holes, crevices, empty barnacle shells, under rocks, and on pilings. Although they occur in the intertidal zone, they are more plentiful subtidally to depths of 435 m (1427 ft) (Garth and Abbott, 1980).

Oregon cancer crabs are usually reddish-brown or orange above and lighter below, with dark-colored claws. The carapace color can vary, however, and in some areas white, mottled, or striped crabs are common (Jensen, 1995). It is a stout, small crab with a carapace width of 31.9 mm (1.3 in.) in males and 47.1 mm (1.9 in.) in females (Garth and Abbott, 1980). (Jensen [1995] reports a size to 53 mm [2.1 in.]). The Oregon crab has ten teeth; the carapace is widest at the seventh and eighth tooth.

In Washington populations (Puget Sound) molting and mating of the Oregon cancer crab occurs from April to June. One brood a year is typical and ovigerous females are most often seen from November through February. The ovigerous females that are occasionally found from April to June are most likely carrying a second brood. The average number of eggs per female is approximately 20,540, with a range between 10,000 and 33,000 (Garth and Abbott, 1980).

Oregon cancer crabs live among beds of barnacles and mussels. Although they feed mainly on these crustaceans and molluscs, polychaete worms, smaller crustaceans, and algae are also consumed. They are primarily carnivores and tend to be more active at night.

The most abundantly impinged shrimp species were three species of bay shrimp: *Crangon nigricauda* (17 percent of the total macroinvertebrates impinged), *Crangon nigromaculata* (7 percent), and *Lissocrangon stylirostris* (7 percent). All three species were collected throughout the year with peak abundance during the winter that was associated with storms. They were impinged primarily at night. Other species of shrimp such as *Pandalus danae*, *Upogebia pugettensis*, and *Peneus californiensis* were impinged in relatively low numbers.

Seven species of cancer crabs were impinged in the following order of abundance: 1) *Cancer antennarius, C. anthonyi, C. productus, C. gracilis, C. magister, C. jordani, and C. oregonesis*. All of these crab species were impinged in substantially higher numbers at Units 1 through 5. Three species (*Cancer antennarius, C. anthonyi, C. productus)* were collected in the greatest numbers and accounted for 37 percent of the catch at Units 1 through 5 but only 9 percent were collected at Units 6 and 7. *Cancer antennarius* was the most abundant (21 percent) of all macroinvertebrates impinged. The frequency of collection of small *Cancer antennarius* suggested that Moss Landing Harbor/Elkhorn Slough provide a nursery habitat for juvenile crabs. *C. anthonyi* constituted approximately 4 percent of all macroinvertebrates impinged. The peak abundance in April was composed of juvenile crabs. *C. productus* constituted less than 2 percent of the total number of macroinvertebrates impinged. Again, the peak (June) in abundance was represented by the presence of small crabs. Dungeness crab were collected in low numbers (24 crabs from Units 1 through 5 and 27 crabs from Units 6 and 7) throughout the year.

Squid constituted less than 5 percent of the total number of macroinvertebrates impinged at the Units 1 through 5 intake and 3 percent at Units 6 and 7. They were collected in every month and did not display a seasonal pattern. The peak number of crabs and squid were impinged in June (68 individuals) at Units 1 through 5 and in October at Units 6 and 7 (70 individuals).

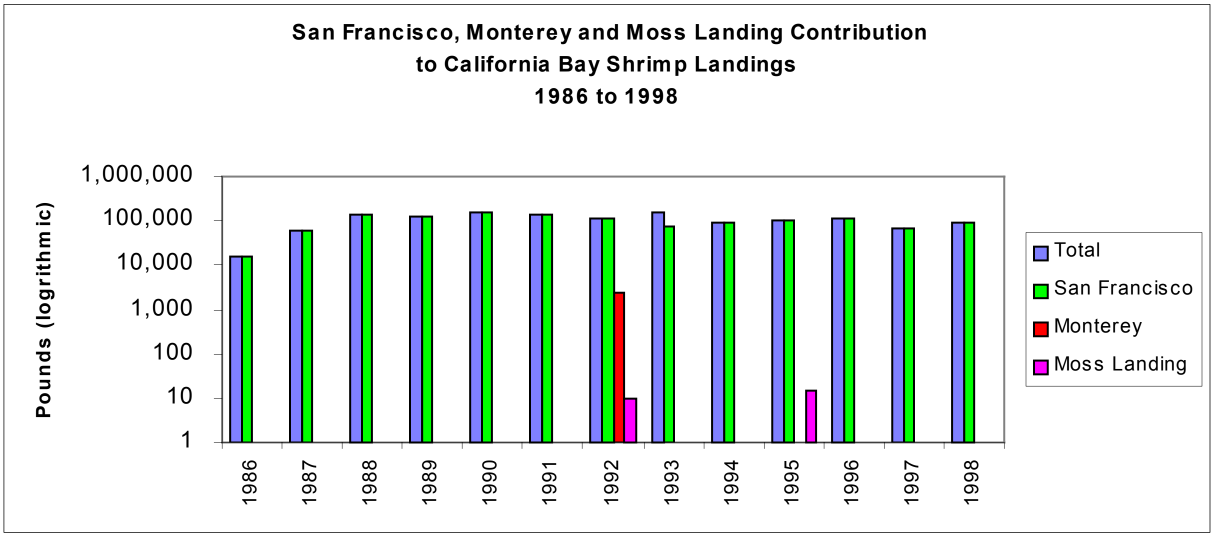
Bay shrimps *Crangon spp.*

Crangon nigricauda, black-tailed shrimp, *Crangon nigromaculata*, black-spotted shrimp and *Lissocrangon stylirostris*, smooth shrimp, commonly known as "bay shrimp" belong to the Family Crangonidae. Shrimp families are easily differentiated from each other by their claw characteristics; crangonids are the only shrimp family to have subchelate claws. These shrimp tend to bury in the sand or mud and are more flattened than other shrimp.

In California today, bay shrimp are fished commercially primarily in San Francisco Bay (Figure 5-4) and are sold mainly as bait. However, in the 1940's and 1950's, annual bay shrimp catches for human consumption averaged 704,000 pounds with peaks as high as nearly 3,000,000 pounds (Chace and Abbott, 1980). *Crangon franciscorum*, Franciscan bay shrimp, were the vast majority of bay shrimp caught commercially until the early 1980's. The black-tailed bay shrimp is currently the most commonly caught species, and the spotted bay shrimp has also increased in abundance since the 1980's (SEW, 1999). Smooth bay shrimp are rarely taken in large numbers (Chace and Abbott, 1980).

Black-tailed shrimp *Crangon nigricauda*

The black-tailed bay shrimp are found from Prince William Sound, Alaska to Isla San Geronimo, Baja California, Mexico. They are commonly found in estuaries, embayments, and in the nearshore ocean environment, ranging from the intertidal zone down to 57 m (187 ft) (Jensen, 1995). Black-tailed shrimp live on sandy and muddy bottoms and are also found around eelgrass beds.



Source: CDFG Landings Summaries 1986–1998.

Figure 5-4. Reported commercial bay shrimp landings in San Francisco, Monterey, and Moss Landing areas from 1986 to 1998.

Crangonids can only be identified to species once they reach a length greater than 10 mm (0.4 in.). Black-tailed shrimp usually become mature after one year, when females are approximately 33mm (1.3 in.) and males are approximately 28 mm (1.1 in.) (CDFG, 1999). Males generally reach a total length of 40 mm (1.6 in.) and females 60 mm (2.4 in.), although greater lengths have been reported in San Francisco Bay and some offshore populations (FWIE, 1999). Females may live two years, while most males die after one year (CDFG, 1999).

The spawning season of black shrimp appears to occur year-round along the California coast, with peaks in winter-spring and summer-fall (FWIE, 1999). The females, carrying eggs under their abdomen, remain partly buried in the sand or mud during the day. The eggs hatch at night, at which time the females emerge and beat their pleopods, creating currents to release the newly hatched larvae. By dawn, most of the larvae have been freed from the female. Fecundity is directly related to the female's size, with an average-sized female producing approximately 3,700 eggs (Krygier and Horton, 1975). Early-stage larvae, found in the surface waters, generally occur in near shore locations while late-stage larvae, found near the bottom of the water column, are more likely to be found in onshore and upstream locations (FWIE, 1999). The planktonic stage lasts from two to five months (Krygier and Horton, 1975).

Black shrimp tend to migrate from concentrations of lower to higher salinity as they mature. As egg stage development in ovigerous females advances from stage one to stage four, the shrimp's occurrence in more saline waters also increases (salinity average of 24.6 ppt for females with stage four eggs) (FWIE, 1999). Higher temperatures lead to larger sizes of bay shrimp, presumably due to faster growth and longer growing seasons Annual abundance of the black-tailed shrimp increased during the drought years (1987 to 1992) and has remained high despite increased freshwater flows and decreased salinities.

Black-spotted shrimp *Crangon nigromaculata*

The black-spotted shrimp is found from the Farallon Islands in northern California to Turtle Bay, Baja California, Mexico (CDFG, 1999). It inhabits shallow coastal waters and is typically found on sand bottoms from 5 to 174 m (16 to 565 ft) (Jensen, 1995). It is more commonly found in nearshore ocean environments than in estuaries. The black-spotted shrimp is migratory and capable of swimming, however it tends to be more epibenthic, remaining in areas of sand and mud.

The black-spotted shrimp is easily recognized by the eyespots on either side of their abdomen. These shrimp can reach approximately 70 mm (2.7 in.) in size (Jensen, 1995). The spawning season of bay shrimp is long, with reports of ovigerous females being found during 9 to 12 months of the year (FWIE, 1999). Periods of peak abundance of black-spotted juveniles in the Bay-Delta area have been highly variable, ranging from late spring to winter. It has been hypothesized that the Bay serves as a continuation of the nearshore nursery area for the black-spotted shrimp (CDFG, 1999).

Since the mid-1980's, the abundance of black-spotted shrimp has steadily increased. It was the second most abundant species of shrimp caught in San Francisco Bay from 1991 through 1993 (CDFG, 1999).

Smooth shrimp *Lissocrangon stylirostris*

The smooth shrimp ranges from Chrikof Island, Alaska to San Luis Obispo Bay, near Avila Beach, California. It occurs most commonly in the subtidal area to about 80 m (262 ft) (Jensen, 1995). Smooth shrimp inhabit the surf zone on wave swept beaches (Jensen, 1995) and are sublittoral in regions of hard sand or mixed rock bottoms (Chace and Abbott, 1980).

Smooth shrimp reach approximately 61mm (2.4 in.) in length (Jensen, 1995). They are the least abundant species of bay shrimp caught by fishermen in San Francisco Bay. Smooth shrimp have been caught in water temperatures ranging from 8.7° to 16° C (47.7° to 60.8° F) and at salinities ranging from 52 to 100 percent seawater (Chace and Abbott, 1980). Smooth shrimp are faster moving than other bay shrimp, probably due to their more challenging environment. They feed on other small crustaceans and clams (Jensen, 1995).

Market squid *Loligo opalescens*

The market squid is a member of the class Cephalopoda; squids and octopuses. Cephalopods are highly organized and the most intelligent of the invertebrates (Hochberg and Fields, 1980). The giant nerve fibers of the market squid are used in neurophysiological research, adding much to our understanding of nerve impulses. Market squid range from southern Alaska to Isla Guadalupe, Mexico, but are more common from British Columbia southward (Hochberg and Fields, 1980). Market squid are pelagic, living in coastal waters but returning to shallow inshore waters to spawn. It is the only species of squid that is abundant inshore (Hochberg and Fields, 1980).

Market squid are translucent blue in color, but vary from a mottled gold and brown to a dark brown or red. They have an ability to change color; this "social signaling" is used for courtship, schooling, feeding, and for camouflage when frightened. Squid have elongated bodies and swim by jet propulsion. Male market squid reach 275 mm (11 in.) in size (not including tentacles) and females approximately 200 mm (8 in.) (UCLA, 1999). Female and male market squid may reach maturity at dorsal mantle lengths (DML) as small as 72 to 81 mm (2.8 to 3.2 in.) (FWIE, 1999). At 15 mm (0.6 in.) DML squid are reported to be approximately 50 days old.

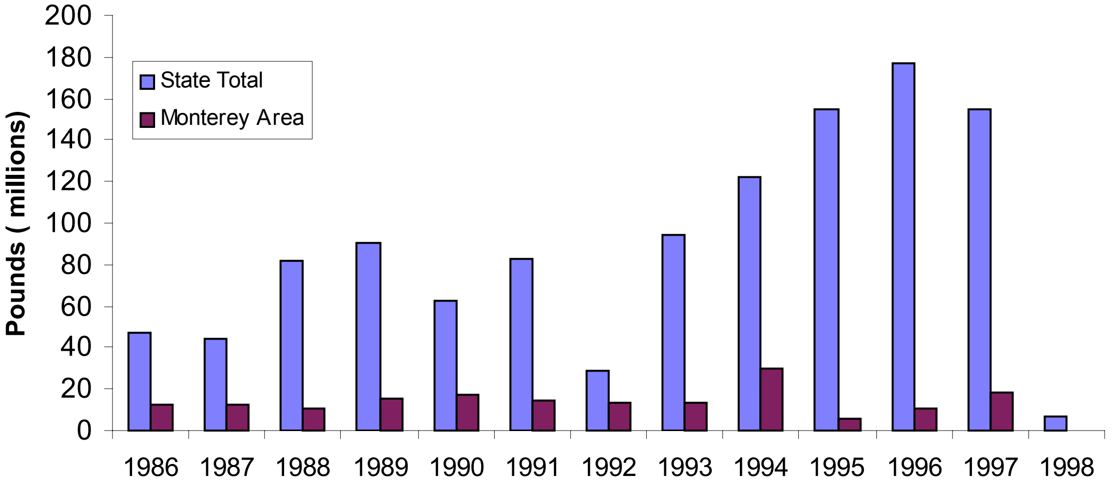
Market squid spawn year-round from San Francisco to Baja, but exhibit biannual spawning peaks (Starr et al, 1998). The majority of spawning activity in southern California squid populations occurs from December through March, but may also occur in July. Squid populations in Monterey Bay spawn mainly in May and June, and to a lesser extent in November (Hochberg and Fields, 1980). Adults migrate from areas over the continental shelf to nearshore sandy and rocky bottom bays, often near submarine canyons, to spawn. Both male and female squid are terminal spawners and die after spawning. Starr et al. (1998) state market squid have a life span of one to two years, while Hochberg and Fields (1980) report most spawners appear to be three years old.

The female produces from 180 to 300 eggs encased in a cylindrical capsule and may extrude 20 to 30 capsules during a spawning event (Starr et al, 1998; FWIE, 1999). The first egg cases to be laid are attached with thin stalks to the bottom substrate. Subsequent layers (approximately 20 to 30 capsules) are then deposited until large clusters are formed (Starr et al, 1998). Egg cases have been observed in depths ranging from 3 to 180 m (10 to 590 ft) (FWIE, 1999). The eggs hatch in 15 to 90 days, depending on water temperature.

Squid do not have a true larval stage; young squid are called hatchlings. The hatchling squid look like miniature adults and have a mantle length of 2.7 mm (0.1 in.) (Starr et al, 1998). Hatchlings live off their yolk sac for several days. They are weak swimmers until they are around 15 mm (0.59 in.) DML, and therefore, can be widely dispersed by currents (FWIE, 1999). At 70 to 80 days old hatchlings have become stronger swimmers and begin to form schools (FWIE, 1999). Juveniles grow rapidly and school for approximately 4 to 8 weeks in semi-protected nearshore areas before beginning to disperse into deep water (Starr et al., 1998).

Squid are carnivores and feed using their tentacles, preying on small crustaceans (euphausiids, mysids, etc.) fishes, polychaete worms, and their own young. Hatchling squid feed on small planktonic crustaceans including crab larvae, copepods, and penaeid shrimp myses (FWIE, 1999). Squid are consumed by many species of fishes, birds, and marine mammals.

Market squid are fished commercially, marketed for human consumption or sold as bait. Figure 5-5 shows the reported Monterey area contribution to the commercial landings for market squid in California from 1986 through 1998. Historically, the squid fishery has been important to the central California coast.



Source: CDFG Landings Summaries 1986–1998.

Figure 5-5. Commercial market squid landings reported for California and Monterey area.

Landings of squid can fluctuate drastically from year to year, but, despite intense fishing pressure, have not exhibited a steady decline that would indicate overharvest (Starr et al., 1998). Squid abundance and harvest is generally low during El Niño years, such as 1983/1984 and 1998/1999. In recent years, market squid landings at Monterey area ports have ranged from over 30 million pounds during a peak year in 1994 to around 185,000 pounds during 1998 (CDFG Landing Summary). Although subject to these great fluctuations, the market squid fishery is frequently among the most profitable fisheries in the Monterey Bay area.

5.3 Impingement Effects

Northern anchovy *Engraulis mordax* was the most abundant fish species collected from both intakes and constituted 61 percent of all fishes impinged. Shiner perch *Cymatogaster aggregata* ranked second in abundance at 9 percent, followed by topsmelt *Atherinops affinis* (9 percent) and Pacific herring *Clupea pallasi* (4 percent). These four species accounted for 83 percent of all fishes impinged during the entire study.

Northern anchovy was the most abundantly impinged fish from both intakes. They were impinged in highest numbers during the summer and early fall months and were present in very low numbers during the winter. Peak impingement occurred in late August and early September at both intakes: 19,077 at Units 1 through 5 and 90,160 at Units 6 and 7. Based on laboratory growth rates, it was surmised that the northern anchovy impinged during the summer and fall were spawned during the previous spring.

Shiner perch was the second most abundant fish collected at Units 1 through 5 (26,000) and the fourth most abundant at Units 6 and 7. They were collected throughout the year but peaked during their spawning period in the spring and summer months. Shiner perch are live-bearers and the majority of shiners impinged were young-of-the-year. It was thought that gravid females may have prematurely released their embryos when the came into contact with the screens.

Topsmelt was the third most abundantly impinged fish at Units 1 through 5 (13,000) and the second most abundant at Units 6 and 7 (16,000); overall this species constituted 8.8 percent of all fishes collected. They were impinged throughout the year, with peak abundance from October through December. Large schools of topsmelt, which may have been associated with spawning activity, were observed in the harbor during the fall and early winter.

Pacific herring was the fourth most abundantly impinged fish and constituted 4.3 percent of all fishes impinged. They were impinged throughout the year with peak densities from June through August, with a second, lower peak in January and February.

Thirteen species of surfperch were collected in impingement samples from the Units 1 through 5 intake, and 12 species from the Units 6 and 7intake. Shiner perch discussed above was the most commonly collected species at both intakes. Other species included white seaperch, and barred, black, dwarf, kelp, pile, rainbow, rubberlip, silver, spotfin, striped, and walleye surfperches. Walleye surfperch were collected throughout the year, with peak numbers impinged in June and July. Most were impinged in the summer and were juveniles. White seaperch were impinged also throughout the year with peaks in abundance between May and July and were mainly juveniles.

Rockfishes were represented in impingement collections by a total of 14 species. The most abundant were olive, blue, grass and brown rockfish and bocaccio. These five species accounted for 89 percent of all rockfishes impinged at Units 1 through 5 and 84 percent at Units 6 and 7. The percentage of bocaccio, the single most abundant rockfish impinged, at Units 1 through 5 (59 percent) was nearly the same at Units 6 and 7 (53 percent). Bocaccio was impinged throughout the year, with the greatest abundance in May through September.

On the basis of the lengths of impinged bocaccio, it was determined that virtually all were young-of-the-year. Figure 5-6 shows the mean length of bocaccio collected in impingement samples at the Moss Landing Power Plant for Units 1 through 5 and Units 6 and 7 intakes (PG&E, 1983). The data show that mean length of the bocaccio measured was less than 180 mm, the maximum length of the young-of-the-year bocaccio (Starr et al., 1998). A part of the total number of bocaccio in the sample was measured. The number of bocaccio measured during each month is listed above each of the figure bars. Figure 5-7a and 5-7b show the number measured vs. total number of bocaccio collected in the impingement samples.

Olive/yellowtail rockfish constituted 14 percent of the rockfish collected from Units 1 through 5 intake and 16 percent at Units 6 and 7. They were collected throughout the year with peak abundance in June and July. Blue rockfish comprised 6 percent of rockfish collected at Units 1 through 5 and 4 percent at Units 6 and 7. The average length for the Units 1 through 5 was 70 mm (2.8 in.) and 67 mm (2.6 in.) at Units 6 and 7. As with the olive/yellowtail virtually all blue rockfish impinged were juveniles.

Impingement surveys were taken at the cooling water intakes for Units 1 through 5 and Units 6 and 7 from January 1979 to March 1980.

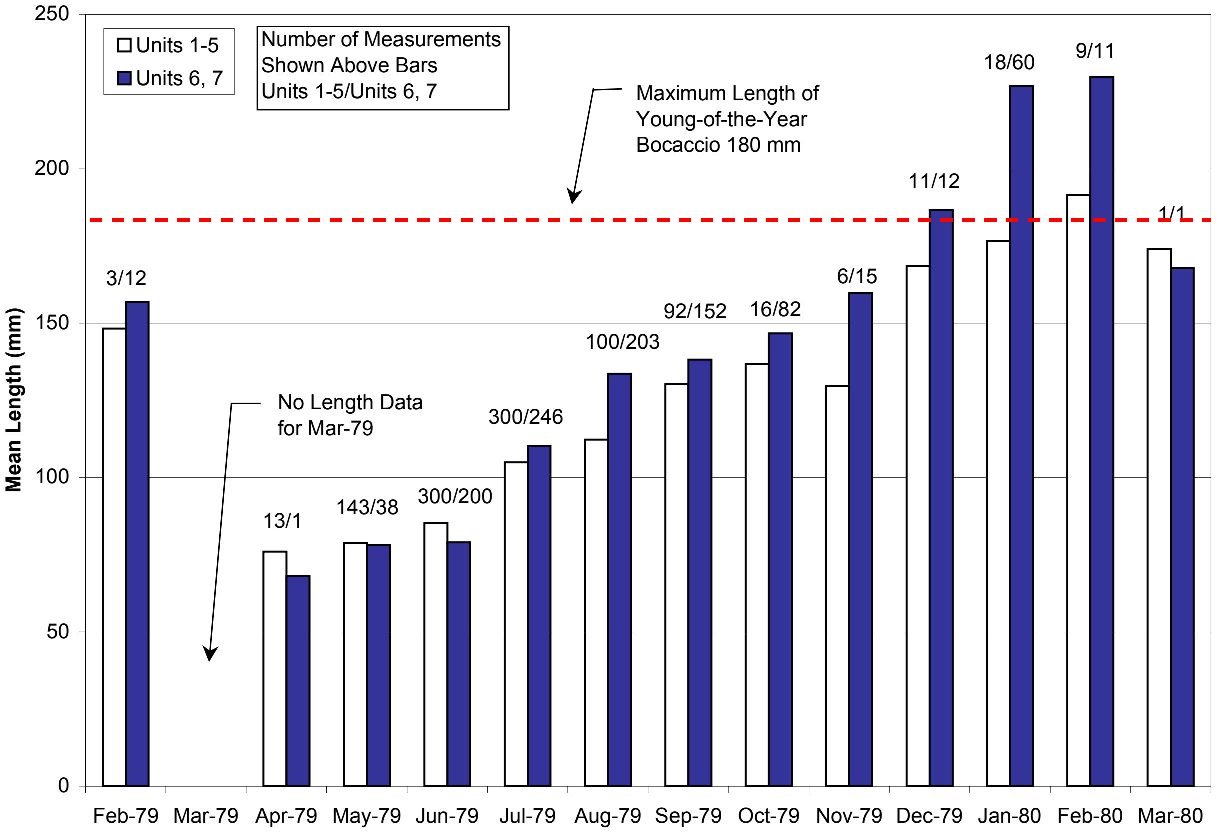


Figure 5-6. Mean length of bocaccio collected in impingement samples at the Moss Landing Power Plant for Units 1 through 5 and Units 6 and 7 intakes (PG&E, 1983).

Figure 5-8 shows the mean monthly concentrations (#/1,000 m^3) for the four most abundantly impinged fishes: northern anchovy, shiner perch, topsmelt, and Pacific herring. The mean

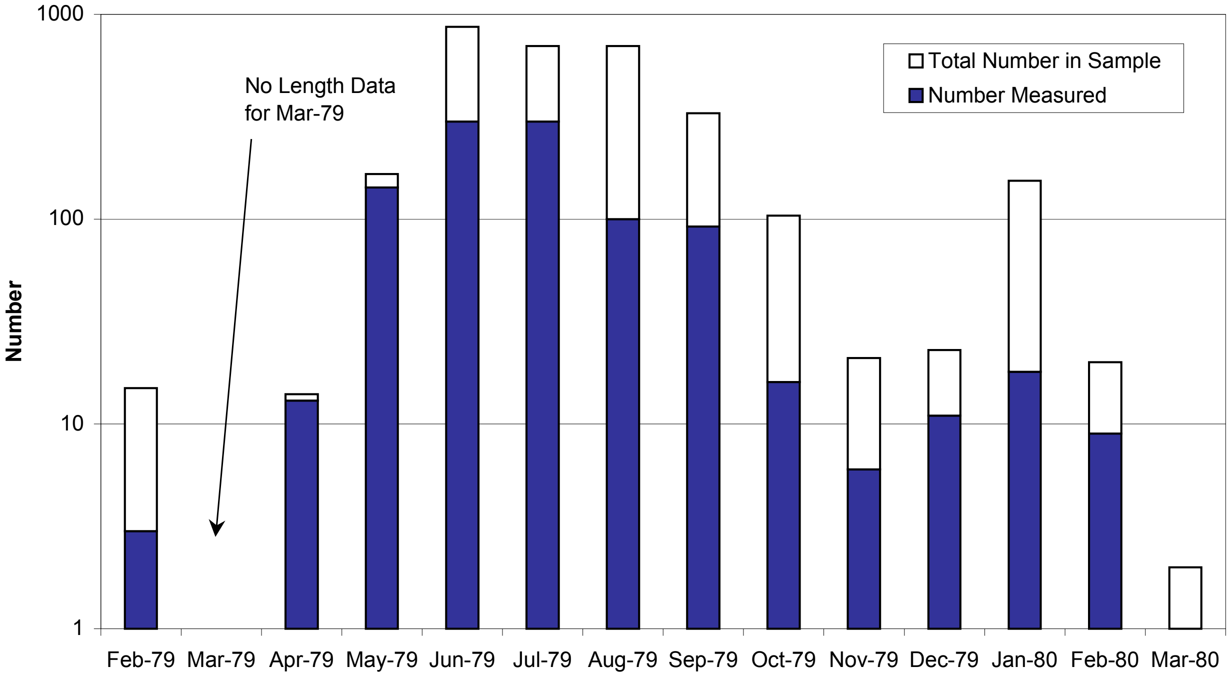


Figure 5-7a. Number measured vs. total number of bocaccio collected in impingement samples at the Moss Landing Power Plant Units 1 through 5 intakes (PG&E, 1983) .

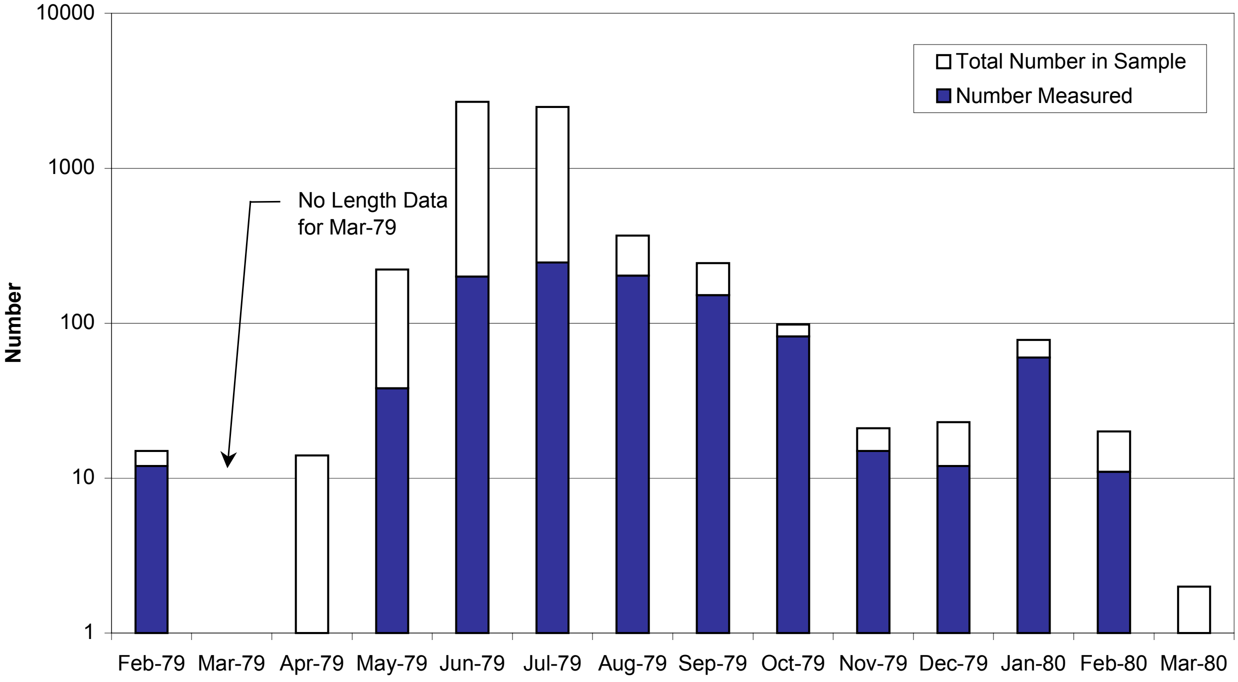


Figure 5-7b. Number measured vs. total number of bocaccio collected in impingement samples at the Moss Landing Power Plant Units 6 and 7 intakes (PG&E, 1983).

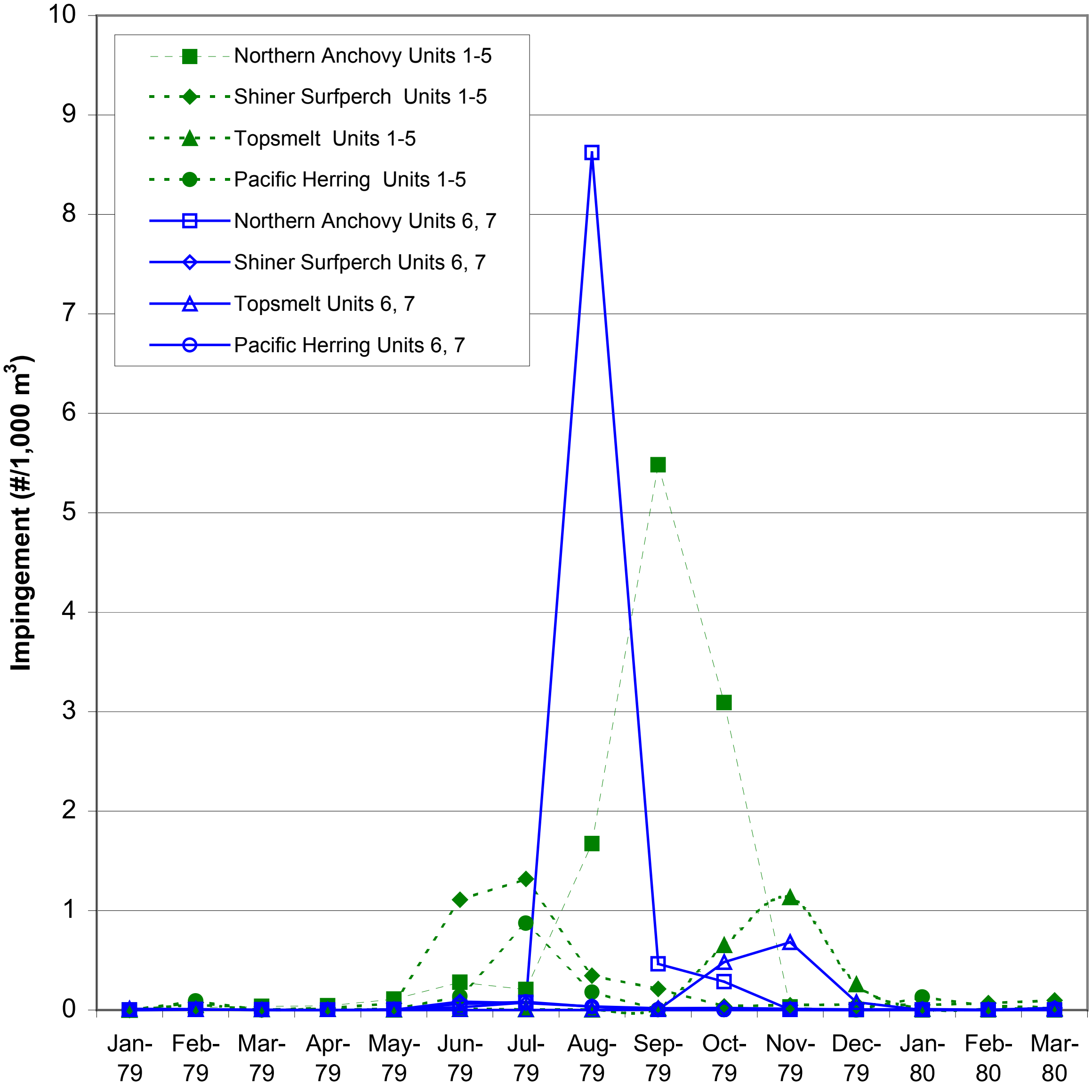


Figure 5-8. Mean monthly concentrations of the most abundantly impinged fishes at the Moss Landing Power Plant Units 1 through 5 and Units 6 and 7 intakes (PG&E, 1983).

monthly concentration was determined by calculating the mean concentration for all of the surveys taken during that month. The survey data illustrate that the highest impingement for the northern anchovy occurred during the late summer and fall. Impingement for shiner perch was high during the summer, whereas topsmelt experienced the highest impingement during the late fall.

Figures 5-9a and 5-9b also show the mean monthly concentrations for the abundantly impinged fishes. However in these figures, the concentration for each of the four species is presented in one record per month. This provides an indication of the total impingement for all abundant fishes as well as the contribution to the total by each of the four species. These figures further illustrate that the highest concentration occurs during the summer and fall seasons.

Figures 5-10a and 5-10b show the mean monthly concentrations for three selected cancer crabs; *Cancer antennarius*, *Cancer anthonyi*, and *Cancer productus*. These figures show that *Cancer antennarius* experiences the highest impingement. *Cancer anthonyi* had the next highest impingement levels throughout the survey period.

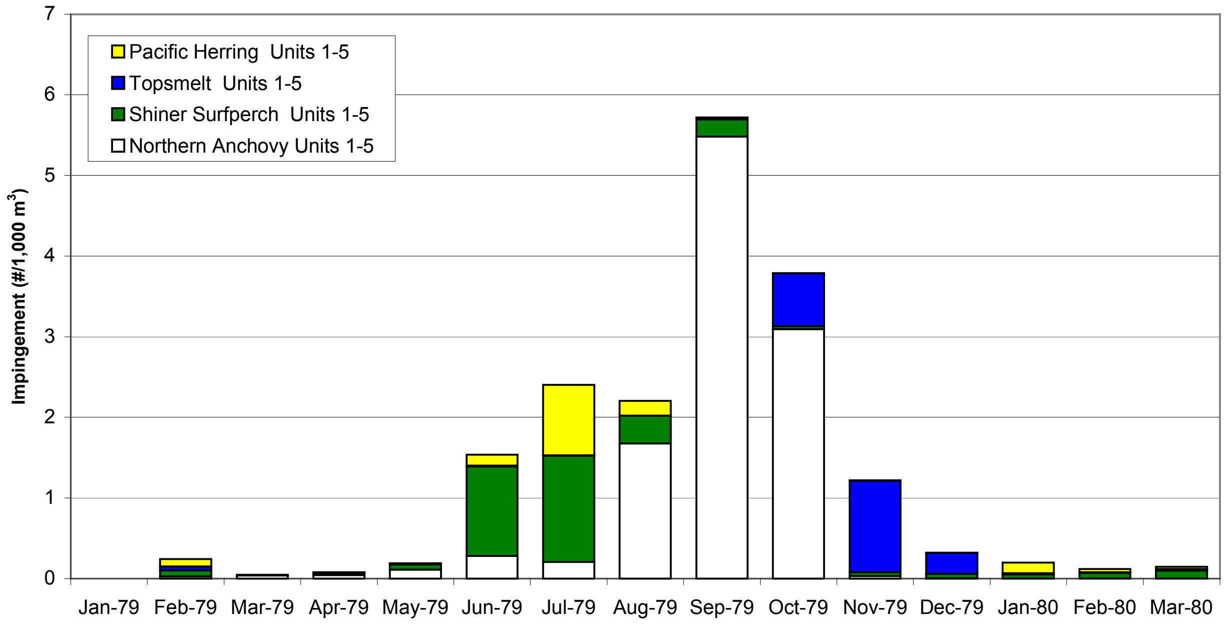


Figure 5-9a. Mean monthly combined concentrations of the most abundantly impinged fishes at the Moss Landing Power Plant Units 1 through 5 intake (PG&E, 1983).

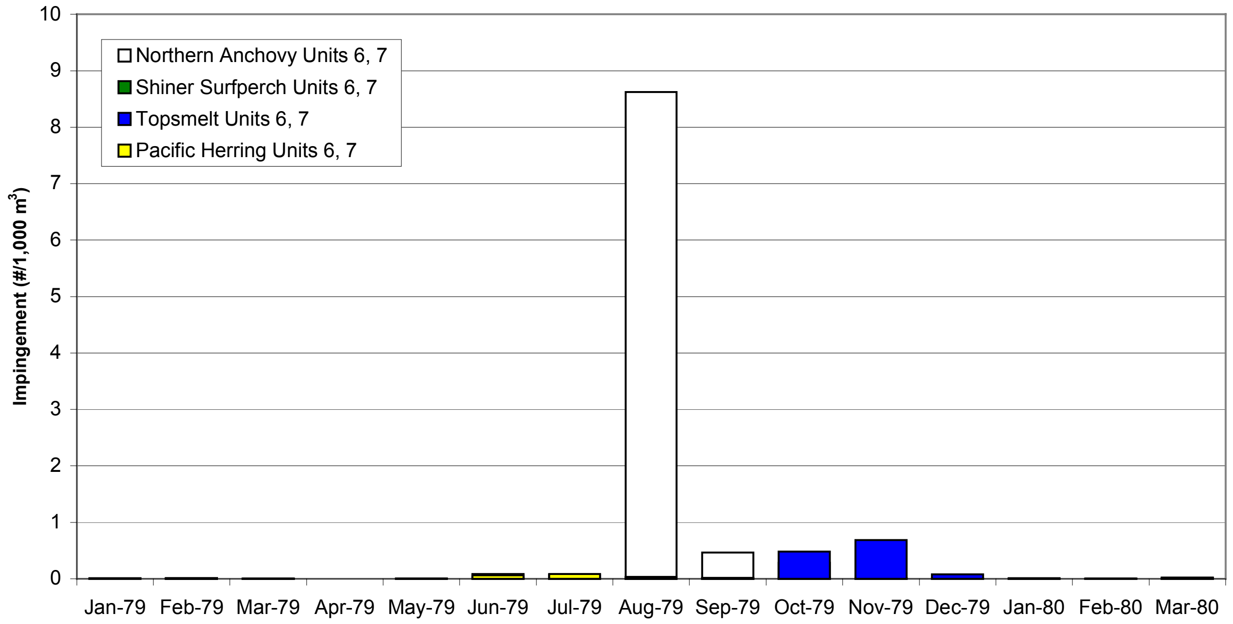


Figure 5-9b. Mean monthly combined concentrations of the most abundantly impinged fishes at the Moss Landing Power Plant Units 6 and 7 intake (PG&E, 1983).

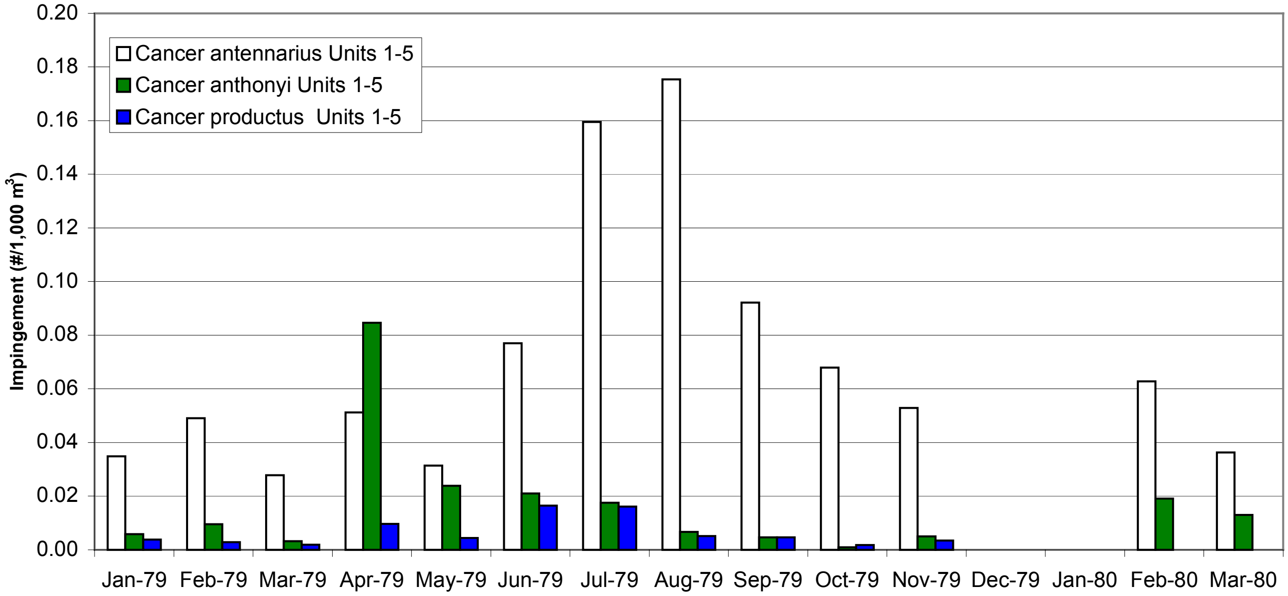


Figure 5-10a. Mean monthly concentrations of the most abundantly impinged *Cancer* spp. crabs at the Moss Landing Power Plant Units 1 through 5 intake (PG&E, 1983).

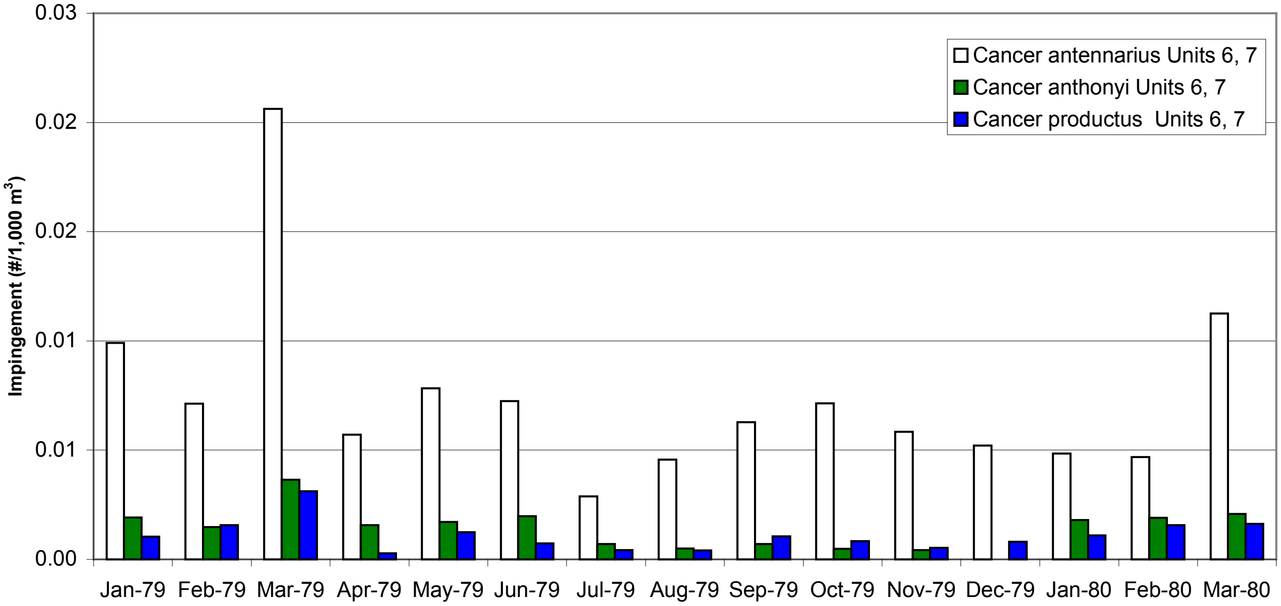


Figure 5-10b. Mean monthly concentrations of the most abundantly impinged *Cancer* spp. crabs at the Moss Landing Power Plant Units 6 and 7 intake (PG&E, 1983).

Table 5-1 lists the estimated concentrations (#/1,000 m^3) based on surveys taken from January 1979 to March 1980. Impingement surveys were taken at the cooling water intakes for Units 1 through 5 and Units 6 and 7. The data for the surveys was used to calculate an estimated concentration and estimated number impinged per day for selected species of fish and macroinvertebrates at each intake.

Table 5-1. Estimated Concentrations based on Surveys taken from January 1, 1979 through March 31, 1980.

	Units 1 through 5		**Units 6 and 7**	
Mean Volume/Day - Survey Dates (1,000 m^3)	1,330		2,322	
Mean Volume/Day - Calendar Year (1,000 m^3)	1,267		2,335	
	Estimated Concentration (#/1,000 m^3)	Estimated Impinged/Day (#)	Estimated Concentration (#/1,000 m^3)	Estimated Impinged/Day (#)
Northern anchovy	0.7882	1,049	0.7230	1,678
Shiner perch	0.3099	412	0.2378	552
Topsmelt	0.1542	205	0.1470	341
Pacific herring	0.1330	177	0.1088	253
Pacific staghorn sculpin	0.0569	76	0.0523	121
Bocaccio	0.0644	86	0.0466	108
Rockfish: Taxon: black rockfish, chilipepper, copper rockfish, cowcod, darkblotched rockfish, dwarf rockfish, kelp rockfish, shortbelly rockfish, vermilion rockfish.	0.0009	1	0.0008	2
Abundant Fish; Northern anchovy, shiner perch, topsmelt, and Pacific herring.	1.3854	1,843	1.2166	2824
Top Macroinvertebrates, Crabs; *Cancer antennarius, Cancer anthonyi, Cancer gracilis, Cancer jordani, Cancer magister, Cancer oregonensis, Cancer productus*, *Cancer* spp.	0.1135	151	0.1019	237

Selected species of fish include abundant fish such as northern anchovy, shiner perch, topsmelt, and Pacific herring. The staghorn sculpin and bocaccio were of interest and were also included in the impingement analysis. Selected rockfish were analyzed as a group including black rockfish, chilipepper, copper rockfish, cowcod, darkblotched rockfish, dwarf rockfish, kelp rockfish, shortbelly rockfish, and vermilion rockfish. Selected species of cancer crabs were analyzed including *Cancer antennarius*, *Cancer anthonyi*, *Cancer gracilis*, *Cancer jordani*, *Cancer magister*, *Cancer oregonensis*, *Cancer productus*, and *Cancer* spp.

The estimated concentration was determined by first calculating the actual concentration for each survey. The estimated concentration was then calculated by taking the mean of the concentration for all of the surveys. The mean cooling water intake volume for all the survey dates was utilized to convert the estimated concentration to an estimated number impinged per day. The estimated number of each species impinged per day was calculated by taking the product of the estimated concentration and the mean volume for all of the surveys.

The northern anchovy had the highest estimated concentration of the selected abundant fish for Units 1 through 5 and Units 6 and 7 (at 0.7882 and 0.7230 /1,000 m^3 respectively). The topsmelt had the second highest estimated concentration at 0.3099/1,000 m^3 for Units 1 through 5 and 0.2378 /1,000 m^3 for Units 6 and 7. Shiner perch had the third highest estimated concentration at 0.1542 and 0.1470 /1,000 m^3 for Units 1 through 5 and Units 6 and 7 respectively. Pacific herring had the fourth highest estimated concentration at 0.1330 and 0.1088 /1,000 m^3.

The remaining species of fish analyzed had relatively low concentrations. Staghorn sculpin had an estimated concentration at 0.0569 (#/1,000 m^3) for Units 1 through 5 and 0.0523 /1,000 m^3 for Units 6 and 7. Bocaccio had an estimated concentration at 0.0644 and 0.0466 /1,000 m^3 respectively for Units 1 through 5 and Units 6 and 7. The selected rockfish had an extremely low estimated concentration of 0.0009 /1,000 m^3 and 0.0008 /1,000 m^3) for Units 1 through 5 and Unit 6 and 7.

The data for the cancer crabs were evaluated as a group. The estimated concentration for the cancer crabs was 0.1135/1,000 m^3 for Units 1 through 5 and 0.1019/1,000 m^3 for Units 6 and 7.

5.4 Rate of Impingement and Intake Velocities

Intake velocities could affect the rate of impingement if there are large amounts of debris present in the water. This relationship between heavy debris loading on the screens and increased impingement was examined at the Morro Bay Power Plant (PG&E, 1982).

Information was provided by Farm Pump Irrigation (FPI) on the expected approach velocities of a traveling screen designed to replace the existing screens at the Pittsburg Power Plant. Following discussions with FPI on various design aspects FPI provided estimates of through-screen velocities for the replacement screen design at Pittsburg Units 1 through 4 and Units 5 and 6 intakes for both high and low tide conditions (Table 5-2). The estimated replacement screen design velocities were compared to previously reported intake approach and through-screen design velocities for Pittsburg Units 1 through 4 and Units 5 and 6. Assuming that the PG&E reported approach and through-screen velocities were calculated for high tide conditions, the replacement of the existing traveling screens with FPI-type screens would reduce both existing approach and through-screen velocities at Units 1 through 4 and Units 5 and 6.

Table 5-2. Existing and Projected Approach and Through-Screen Velocities for the Pittsburg Power Plants Units 1 through 4 and Units 5 and 6 Intakes.

	Approach Velocity (fps)		**Through-screen Velocity (fps)**	
	Existing	**FPI Replacement**	**Existing**	**FPI Replacement**
Pittsburg Power Plant				
Units 1 through 4	0.8 (0.24 mps)	0.65-1.11 (0.198-0.34 mps)	2.0 (0.61 mps)	0.75 (0.23 mps)
Units 5 and 6	0.8 (0.24 mps)	0.60-1.05 (0.183-0.32 mps)	1.5 (0.46 mps)	0.69 (0.21 mps)

The impacts of power plant intake velocities on fishes have been widely reviewed and published. The U.S. Fish and Wildlife Service has provided the general background and understanding to assess impacts of intake velocities on fisheries resources. Their publications conclude with a recommendation that maximum intake velocities should not exceed 0.5 fps. There are number of factors which go into estimating general guidance for approach velocities. However, conditions vary from site to site, with age class of fish and species of fish. The basis for the 0.5 fps recommendation has been investigated for a number of species and sizes in specific intake situations. The effect of screen approach velocity on percent impingement of larval and juvenile striped bass in laboratory swimming trials for periods of 10 and 30 minute duration is shown in Table 5-3.

Table 5-3. Impingement of Striped Bass at Various Approach Velocities.

Percent Striped Bass Impinged versus Approach Velocity							
Test time and size range	**Velocity (fps)**						
19–38 mm length	0.8 (0.24 mps)	0.9 (0.27 mps)	1.0 (0.30 mps)	1.1 (0.34 mps)	1.2 (0.37 mps)	1.3 (0.40 mps)	1.4 (0.43 mps)
10- min	0	0	20	40	60	79	97
90–140 mm	0.5 (0.15 mps)	0.75 (0.23 mps)	1.0 (0.30 mps)	1.5 (0.46 mps)	2.0 (0.61 mps)	2.5 (0.76 mps)	
10-min	0	0	0	0	8	29	
30-min	0	0	2	11	32		

Source: EA, 1982

Intake velocity calculations, based on an inclined screen-type replacement for the Pittsburg Power Plant, indicate that during high tide the existing approach velocities would decrease. Units 1 through 4 approach velocities would decrease from 0.8 fps (0.24 mps) to 0.65 fps (0.20 mps) and approach velocities would decrease from 0.8 fps (0.24 mps) to 0.60 fps (0.18 mps) at the Units 5 and 6 intake. Based on the information provided in Table 5-3, this reduction in intake velocity would have no measurable effect on the impingement of fishes similar to striped bass. The reduced velocities might benefit more fragile fish species.

5.4.1 Impingement Survival and Intake Velocities

The reduction of intake and screen approach velocities will increase the potential of small fish surviving impingement. Replacement of the existing Units 1 through 5 traveling screens with lower velocity inclined-type screens would increase the potential for survival of impinged fishes, assuming that:

1. fine mesh screen was used to remove small fishes, and
2. the fishes were returned to the source water within a few minutes.

The potential to reduce fish losses by reductions in traveling screen approach velocities is illustrated in Table 5-4.

Table 5-4. Survival (%) of Striped Bass Impinged Four Minutes at Various Water Velocities.

Survival (%) of Striped Bass Impinged Four Minutes at Various Water Velocities			
Size Class (mm)	**Velocity (fps)**		
	0.5 (0.15 mps)	1.0 (0.30 mps)	1.5 (0.46 mps)
5.1-6.9	69 %	62 %	19 %
7.0-8.9	83 %	84 %	71 %
9.0-10.9	91 %	90 %	90 %
11.0-12.9	96 %	88 %	88 %
13.0-14.9	89 %	94 %	87 %
15.0-16.0	100 %	96 %	100 %
Weighted Mean	83 %	80 %	68 %

Source: Alden Research Laboratory and Stone and Webster Engineering Corporation (1980), as cited in Ecological Analysts, Inc., 1982.

Note: Impingement survival was determined 96 hours after impingement and has not been corrected for control survival. No tests were conducted using fish < 16 mm (0.63 in.) at an approach velocity of 0.5 fps (0.15 mps).

Since the sizes of fish that benefit most from reduced impingement velocities are fish smaller than the ones impinged by MLPP's existing 3/8 in. (0.953 cm) mesh screens, the effect of inclined-type screen replacement on impingement survival would be minimal, if any, and difficult to quantify. The above table shows an example of impingement survival represented by a relatively hardy species, striped bass. The impingement survival of larger sizes and adult forms of more fragile species of fish, such as Pacific herring, would potentially increase with reduced intake screen approach velocities.

Impingement survival studies (PG&E, 1983) were designed to provide a quantitative basis for estimating the survival of fishes and macroinvertebrates. Impingement survival was determined for the following three modes of traveling screen rotation operation: continuous, 1-hour intermittent, and 3-hour intermittent. The different rotation modes limited the amount of time impinged organisms were held on the screens. Organisms were collected and initial observations of alive or dead were recorded. Animals were placed into a flow-through holding system containing ambient water. They were observed periodically throughout the 96-hour holding period. Control experiments were conducted to determine the mortality associated with the sluiceway collection, handling, and the holding systems methods used. Fishes were mainly collected from otter trawls conducted in Moss Landing Harbor. These control fishes were held for 2 to 4 days before testing to allow them to recover from collection and handling stresses.

Initial and long-term survival of northern anchovy, Pacific herring and silversides were characteristically low at both intakes. Increasing the frequency of screen rotation at Units 6 and 7 improved the survival of surfperch but did not have much effect at Units 1 through 5. Although the survival of flatfish increased with increased screen rotation, the numbers of fishes available testing were low. Long-term survival of gobies and sculpin was high after the 3-hour rotation. Survival of crabs was high from Units 6 and 7, although the number tested was small; Units 1 through 5 crab survival was only 47 percent with 3-hour rotation, which increased to 70 percent and 74 percent for the 1-hour and continuous rotation mode, respectively. It is important to note that these studies were done of organisms collected from the sluiceways of the intakes and were not performed on organisms returned to the Units 6 and 7 discharge. Impinged material from Units 1 through 5 was not routed out through the discharge in Elkhorn Slough, thus no impinged organisms survived.

5.5 Conclusions

The authors of the first 316(b) Demonstration (PG&E, 1983) used recent trends in the commercial fishery landing statistics for the Monterey Bay region to assess entrainment and impingement effects. For example, the trend in commercial landings of northern anchovy, the most abundantly impinged and entrained fish was showing a general increase during the 1970s. Northern anchovy also was the largest (in terms of biomass) fishery in California during the time of the 316(b) work. It was concluded that it was unlikely that the northern anchovy population could have supported such an increased commercial harvest trend if entrainment and impingement had precluded the maintenance of the existing population. Northern anchovy are a pelagic schooling species found from Baja California, north to Alaska. It was also noted that due to the broad distribution and high reproductive potential of northern anchovy, they appeared to be capable of sustaining the incremental mortality associated with a large commercially harvested species.

Gobies are bottom-dwelling or burrow-inhabiting fishes found in the subtidal and intertidal areas in the vicinity of the MLPP. Several species of gobies have been collected in larval and adult fish surveys of the area (Nybakken, Cailliet, and Broenkow, 1977). These species include: bay goby, arrow goby, blackeye goby, yellowfin goby, and longjaw mudsucker. There is no commercial fishery for gobies. Because no information existed on trends in abundance and distribution the authors used life history information to assess potential impacts. They reported, from the literature, that gobies have a moderately high reproductive potential, a high natural mortality rate, are widely distributed, and are not subjected to sport or commercial harvesting. It was also noted that extensive habitat exists in the vicinity of the plant and that because of their bottom-dwelling habits, very few reproductive adults were susceptible to impingement.

Therefore, it can be predicted that the impingement losses for species considered were negligible for the MLPP operating at higher intake volumes than proposed for the modernization. No trends were found in the area's commercial and sport fisheries, including those near the plant, to indicate an adverse impact due to impingement losses at the power plant. Since impingement effects on area-wide fisheries were qualitatively undetectable, it was concluded that existing MLPP intake technology represented BTA to minimize impingement effects and potential impacts.

In summary, modifications to the new combined-cycle intake will reduce impingement. The cooling water volume pumped through the new combined-cycle intake structure will be reduced from 381,000 gpm (1,441 m^3/min) to 250,000 gpm (946 m^3/min). As a result of the lower flows, approach velocities will decrease from 0.9 feet per second (fps; 0.27 meters per second [mps]) to 0.5 fps (0.15 mps). The new traveling screens will be inclined at an approximate angle of 73° from horizontal, thus providing more surface screen area that will result in lower though screen velocities. These new angled screens will be more effective at removing debris than the conventional vertical traveling screens and will reduce the amount of debris in the area of the intake. The existing intake tunnel will be drastically reduced from approximately 350 ft (106.7 m) long to approximately 10 feet (3.1 m) behind the bar racks. The shortening of the tunnel may help to reduce impingement of schooling fishes that can become trapped in the tunnel and subsequently impinged.

6.0 COOLING WATER SYSTEM IMPACT ASSESSMENT

The entrainment and impingement effects of the cooling water system for the proposed MLPP combined-cycle (CC) project have been assessed on the basis of both historical and on twelve months of recently completed survey information. The assessment considers both the effects of entraining larval fishes and megalopal cancer crabs and impinging larger fishes and invertebrates in the cooling water intake structure (CWIS).

The three methods for assessing cooling water system (CWS) effects described in the MLPP Modernization Project Study Plan were the fecundity hindcasting (*FH*) and adult equivalent loss (*AEL*) approaches and empirical transport modeling (*ETM*). This report contains estimates of *AEL* and *FH* where data were available to parameterize these demographic approaches. It also provides estimates of proportional entrainment (*PE*) for inclusion in the *ETM*. The estimates of total entrainment mortality (P_M) generated from the *ETM* represent 9 months of the data; it is unlikely that the remaining three months of data will significantly change results presented here.

Results from the MLPP entrainment studies and previous impingement studies (PG&E, 1983) are used to predict the potential entrainment and impingement effects of the proposed combined-cycle CWS. Estimates of larval fish and megalopal cancer crab concentrations ($\#/m^3$) sampled at the MLPP CWIS and multiplied by the projected combined-cycle daily intake volume (m^3) provide estimates of the total number of larval fishes and megalopal cancer crabs that might be withdrawn by the power plant's CWS. Similarly, larval fish and megalopal cancer crab concentrations estimated from MLPP's source water bodies (Elkhorn Slough, Moss Landing Harbor, and Monterey Bay) and multiplied by their daily tidal volumes produce estimates of local larval and megalopal abundance. By comparing the number of larvae and megalops withdrawn by the power plant to the number available (i.e., at risk to entrainment), an estimate of fractional loss (*PE*) can be generated for each taxon or species. The magnitude of these fractional losses can serve as a guide to determining unacceptable CWS effects that could cause population impacts in the form of long-term declines. The context required to interpret these fractional losses comes from fishery management practices and other forms of stock assessments. In the case of a harvested species, these fractional losses must be considered as additive to harvest losses when assessing impacts and any potential for population decline.

In the following description and discussion of our preliminary findings, several consistent trends are apparent. These include low diversity of entrained species and relatively low magnitude proportional losses. In addition to the low diversity of entrained species and small proportional losses, the survey results show very little entrainment of important commercial or recreational species.

Historical information and present findings on MLPP CWS effects and projected effects of the new combined-cycle facility are reviewed and assessed for eight of the most abundant larval fish taxa and all megalopal cancer crabs. The eight fish taxa comprised over 95 percent by abundance of the larvae entrained. Following this assessment of MLPP CWS effects, a variety of alternative intake technologies to reduce these entrainment and impingement effects are reviewed in Section 7—Evaluation of Alternative Intake Technologies. Both the feasibility and cost of the various technologies are weighed against their effectiveness to reduce any identified CWS effects or potential impacts. The economic cost of reducing CWS impacts through implementing alternative technologies must not be wholly disproportionate to the benefit gained in terms of minimizing any adverse environmental impacts.

6.1 Entrainment Effects Assessment

For this report, we have focused our assessment of entrainment effects on the eight most abundant larval fish taxa and all cancer crab megalops. These selected species are carried forward in our analysis as target species because of their high relative abundance or commercial/recreational importance. The larval fish species or taxa groups chosen for this preliminary assessment are the most abundant found in our entrainment sampling to date. They are the unidentified gobies, bay goby, blackeye goby, Pacific staghorn sculpin, white croaker, blennies, longjaw mudsucker, and Pacific herring. Two species that occurred in relative low abundance, Pacific herring and white croaker, were included in the assessment because they represented the only fish species of commercial or recreational value for human consumption collected in our entrainment samples. However, as discussed in the following assessment of the two species, their low abundance makes it nearly impossible to quantitatively assess any MLPP entrainment effects or potential population-level impacts. The *Cancer* spp. megalops assessed are hairy rock crab, yellow rock crab, brown rock crab, dungeness crab, red rock crab, and slender rock crab. The yellow rock crab, brown rock crab, dungeness crab, and red rock crab all have some commercial importance.

The assessment evaluates first the effects of MLPP CWS entrainment on larval forms of fishes and cancer crab megalops followed by a narrative assessment of impingement effects and the potential reduction of these effects by the modernization of the combined-cycle intake structure and flows.

Source Water Volume

The calculation of *ETM*, illustrated in Equations 9 to 14, requires estimates of the number of larvae and megalops entrained, the number of larvae and megalops in the source water population at risk to entrainment, and an estimate of larval age at entrainment. The number of larvae and megalops entrained is estimated from representative samples of entrained organism concentrations multiplied by the total volume of the power plant's intake water. The number of source water larvae and megalops at risk is estimated by multiplying representative samples of their source water population concentrations by source water volumes. Larval ages are estimated from literature-based growth rates and reported lengths at the early life stages of hatching, yolk-sac stage completion, flexion, and transformation (Wang, 1986; Moser, 1996). Megalopal duration, megalopal survival, and age at maturation were estimated from the literature for cancer crabs.

The MLPP source water area was divided into three sub-areas for the purposes of study and analysis. Information on MLPP area's marine geography, hydrography, and ecology was employed in analysis and discussion with the TWG to define *a priori* three sub-elements of source water population at risk to entrainment. The defined elements of source water population are Monterey Bay, Moss Landing Harbor, and Elkhorn Slough. The shallow tidal channels and tributaries of the Elkhorn Slough, which flood and drain extensive *Salicornia* marsh, eelgrass beds, and mudflats, provide habitat for assemblages of invertebrates and fishes characteristically different from those found in the Moss Landing Harbor's habitats of deep channels surrounded by wharves and pilings. The enormous depths of the Monterey Canyon lie just beyond the harbor's entrance into the Monterey Bay. Less than a mile offshore canyon depths can exceed one mile. North and south of the harbor entrance, the steep, often rocky walls of this canyon rise, becoming the broad, shallow depths of sand beach and mud that characterize the majority of the bay's nearshore area from Santa Cruz to Monterey. The two distinctly different bottom substrata in combination with open-ocean beach and submarine canyon oceanographic conditions provide habitat for a third assemblage of invertebrates and fishes.

The methods used to calculate the volumes of each of the three source water elements and their estimated source water volumes are given in Section 3.4.2.1. The geographical location and extent of the three source water sub-areas are illustrated in Figure 3-2.

Source Water Sub-area	Volume (m^3)
Monterey Bay	275,000,000
Elkhorn Slough	21,100,000
Moss Landing Harbor	2,200,000
Combined-Cycle Units (maximum volume)	1,360,000

Empirical Transport Model (*ETM*) outputs are presented along with *PE* estimates for the June 1999 through February 2000 source water surveys. Proportional entrainment (*PE*) values were calculated prior to *ETM* values. The two values differ by the method used to estimate the extent of source water population at risk in time and space. For example, *PE* values calculated for the Monterey Bay source water element approximated its volume as that contained in an area 2 km south and north of the harbor entrance, extending from the shoreline out to a depth of 50 m. Given the presence of strong longshore currents and upwelling in this area, it was assumed that source water populations of larval and megalopal species in this element extend by current transport well beyond our first order approximation of source water extent and volume. However at this time, we have not employed current speed and larval duration to enlarge our initial estimate of Monterey source water volume. Our *ETM* calculations are based on our initial approximation of bay volume. As described in Section 3, the TWG requested that we calculate a second set of *ETM* values substituting the harbor and slough source water volume for the Monterey Bay source water volume. *ETM* values based on this order of magnitude volume difference are presented together with values computed using Monterey Bay's source water volume. In computing *ETM* values, *PE*'s are also weighted by the monthly survey fraction (f_i) of source water population at risk. This factor can significantly affect the outcome of combining a series of *PE* values. An *ETM* value could not be computed for dungeness crab due to a lack of co-occurrence of megalops in entrainment and source water samples. The majority of *ETM* values for the other crab species were based on a single *PE* value.

Demographic Approaches for Estimating Entrainment Effects

Entrainment losses were estimated from total larval and megalopal entrainment at MLPP using fecundity hindcast (*FH*) and adult equivalent loss (*AEL*) models. These models require species-specific estimates of age, growth, fecundity, and survivorship. These data were available for four of the eight target fish taxa: bay goby, blackeye goby, combtooth blenny, and Pacific herring. For bay goby, no species-specific estimates of survival were available in the literature. Therefore, we were unable to estimate *FH* for this species, but were able to estimate *AEL* by substituting juvenile and adult survivorship data on three sympatric gobiids from Brothers (1975). For the other taxa, either species-specific fecundity or mortality rates were available to parameterize one or both of the demographic approaches for estimating entrainment effects. These taxa included white croaker, Pacific herring, hairy rock crab, yellow rock crab, brown rock crab, dungeness crab, red rock crab, and slender rock crab. *AEL* and *FH* loss estimates could not be computed for Pacific staghorn sculpin due to a lack of demographic information. The derivations of these approaches are detailed in Section 3 and the available life history data are summarized for each taxon in Section 4 of this document.

6.2 Unidentified Gobies

The unidentified goby category comprised the largest number and highest density of all entrained taxa. Evidence from our recent analysis of this taxon, discussed in Section 4, suggests that there may be at least two species of gobies in this unidentified category. Because of their common abundance in habitat found in the Moss Landing area, arrow goby probably make up the majority of the larvae in this category. Previous investigators have presumed so in earlier studies of the Elkhorn Slough and Moss Landing Harbor (Nybakken et al., 1977). A closer taxonomic examination of our samples has revealed that many unidentified gobiidae larvae are very similar meristically and morphometrically to the description of arrow goby larvae in Wang (1986) and Moser (1996). However, two prominent peaks in unidentified goby concentration (Figure 4-8), one in upper Elkhorn Slough and another in the ocean at the far extreme of our study area, suggests the possibility of two different species in the unidentified goby category.

This finding brings out a very important point in the application of impact assessment methods. Although we can analyze the proportional loss of a grouped taxon such as unidentified gobies, as we have done in this section, it is not possible to assign the significance of these losses to a particular species' population. However, if we find that the entrainment losses of an unidentified taxon are proportionally low compared to our estimates of source supplies, it provides a measure of assurance that the population of the unknown species we have collected will not be adversely affected by entrainment. Even though the samples may contain more than a single species, if the proportion of species in the unidentified category remains the same among entrainment and source water samples, our estimate of CWS effects and impacts is unaffected. We simply will not know to what species they apply.

Empirical Transport Model (*ETM*)

The proportional entrainment values for unidentified gobies are far below any value that could represent consequential intake effects or potential for long-term population declines. The range of *PE* values and standard errors are summarized in Table 6-1a and b for the nine surveys from June 1999 through February 2000. The *ETM* value, based on the combined Monterey Bay source water volume is 0.03 and the *ETM* value substituting harbor/slough source water volume for bay volume is 0.11.

Table 6-1a. Final *ETM* Output Unidentified Gobies Gobiidae spp. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.02638	0.00423	0.02638	0.02638

Survey Date	*PE* Period Start	*PE* Estimate.	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00624	0.00131	0.14475	0.00278	5.69
12 Jul 1999	18 Jun 1999	0.00131	0.00058	0.09099	0.00065	5.69
12 Aug 1999	13 Jul 1999	0.00444	0.00116	0.02686	0.00012	5.69
16 Sep 1999	13 Aug 1999	0.01133	0.00485	0.04359	0.00020	5.69
14 Oct 1999	17 Sep 1999	0.00048	0.00036	0.05047	0.00046	5.69
18 Nov 1999	15 Oct 1999	0.00481	0.00051	0.19441	0.00094	5.69
29 Dec 1999	19 Nov 1999	0.00478	0.00113	0.15840	0.00097	5.69
20 Jan 2000	30 Dec 1999	0.00325	0.00046	0.06911	0.00138	5.69
24 Feb 2000	21 Jan 2000	0.00504	0.00024	0.22143	0.00161	5.69

Note: Data are preliminary.

Table 6-1b. Final *ETM* Output for Unidentified Gobies *Gobiidae* spp. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.10690	0.00668	0.10690	0.10690

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00978	0.00221	0.14475	0.00278	5.69
12 Jul 1999	18 Jun 1999	0.00448	0.00109	0.09099	0.00065	5.69
12 Aug 1999	13 Jul 1999	0.02455	0.00486	0.02686	0.00012	5.69
16 Sep 1999	13 Aug 1999	0.01329	0.00596	0.04359	0.00020	5.69
14 Oct 1999	17 Sep 1999	0.00132	0.00093	0.05047	0.00046	5.69
18 Nov 1999	15 Oct 1999	0.02961	0.00307	0.19441	0.00094	5.69
29 Dec 1999	19 Nov 1999	0.01799	0.00431	0.15840	0.00097	5.69
20 Jan 2000	30 Dec 1999	0.01719	0.00221	0.06911	0.00138	5.69
24 Feb 2000	21 Jan 2000	0.03156	0.00195	0.22143	0.00161	5.69

Note: Data are preliminary.

Fecundity Hindcast Model (*FH*)

The total annual larval entrainment for unidentified gobies was used to estimate the number of breeding females needed to produce the number of larvae entrained shown in Table 6-2. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained larvae is calculated assuming an age at maturation of 1.0 year and an average lifespan of 2.5 years. The number of adult females hindcast from the larvae entrained at MLPP combined-cycle intake was 300,006 (90 percent C.L. = 97,113 to 926,792).

Table 6-2. Annual Entrainment Estimates for Unidentified Gobies Gobiidae spp.: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
268,968,000	3,206,740	1%

***FH* Estimates Unidentified Gobies *Gobiidae* spp.**

FH Estimate	*FH* Std. Error	Egg Survival	Yolk Sac Survival	Larval Survival	Eggs per Year	Average lifespan (yrs)	Age at Maturation
300,006	205,705	1.0	1.0	0.683078	1,750	2.5	1.0

Upper *FH*	Lower *FH*
90% C.L.	90% C.L.
926,792	97,113

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity, and larval survivorship, in that order.

Adult Equivalent Loss (*AEL*)

No independent estimate of survival of unidentified gobies between age of entrainment and adult stage was available in the literature.

The species of gobies that may comprise this taxon have neither commercial nor recreational fishery value, and there is little information on their ecological role in the community. There are no catch data that can be used to compare harvest mortality rates to entrainment mortality rates because of the absence of fishery data for this species. No estimates of stock size or density are available to convert entrainment mortality rates into an estimate of adult equivalent loss, assuming no compensatory mortality.

Results of *ETM* analyses using the two different source water volumes show that the power plant may annually entrain approximately 3 percent (Table 6-1a) or 11 percent (Table 6-1b) of the unidentified Gobiidae taxon larvae from the MLPP source water. An independent estimate of *FH* yields a predicted theoretical loss of 97,113 to 926,792 adults (females only).

6.3 Bay Goby

The proportional entrainment values for the bay goby have remained quite low throughout the nine months of source water and entrainment studies as shown in Table 6-3. The range of values from a *PE* of zero to 0.03 (Table 6-3a) and zero to 0.17 (Table 6-3b) have remained at these low levels in spite of large fluctuations in the estimated number of entrained gobies. In 8 of the 9 entrainment surveys that coincided with source water surveys, the numbers of bay goby increased in the late evening entrainment cycles after the daytime source water sampling (Figure 4-10).

Empirical Transport Model (*ETM*)

The *ETM* values for bay goby found in Table 6-3 are far below values that would represent consequential intake effects or any potential for long-term population declines. The *ETM* value based on Monterey Bay source water volume is 0.04 and 0.21 when harbor/slough source water volume is substituted for Monterey Bay source water volume. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project's CWS on the area's populations of bay goby.

Table 6-3a. Final *ETM* Output Bay Goby *Lepidogobius lepidus*. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.03862	0.00878	0.03862	0.03862

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.02279	0.00087	3.29
12 Jul 1999	18 Jun 1999	0.00181	0.00048	0.02787	0.00053	3.29
12 Aug 1999	13 Jul 1999	0.00214	0.00298	0.03156	0.00015	3.29
16 Sep 1999	13 Aug 1999	0.02912	0.01805	0.05694	0.00032	3.29
14 Oct 1999	17 Sep 1999	0.00126	0.00054	0.05964	0.00040	3.29
18 Nov 1999	15 Oct 1999	0.00595	0.00114	0.28503	0.00126	3.29
29 Dec 1999	19 Nov 1999	0.00945	0.00640	0.25217	0.00152	3.29
20 Jan 2000	30 Dec 1999	0.01792	0.00720	0.11026	0.00250	3.29
24 Feb 2000	21 Jan 2000	0.02671	0.00873	0.15374	0.00245	3.29

Table 6-3b. Final *ETM* Output for Bay Goby *Lepidogobius lepidus*. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.21442	0.04058	0.21442	0.21442

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.02279	0.00087	3.29
12 Jul 1999	18 Jun 1999	0.01654	0.00441	0.02787	0.00053	3.29
12 Aug 1999	13 Jul 1999	0.02055	0.02575	0.03156	0.00015	3.29
16 Sep 1999	13 Aug 1999	0.04901	0.03268	0.05694	0.00032	3.29
14 Oct 1999	17 Sep 1999	0.00589	0.00207	0.05964	0.00040	3.29
18 Nov 1999	15 Oct 1999	0.03972	0.00683	0.28503	0.00126	3.29
29 Dec 1999	19 Nov 1999	0.06821	0.04845	0.25217	0.00152	3.29
20 Jan 2000	30 Dec 1999	0.13367	0.03869	0.11026	0.00250	3.29
24 Feb 2000	21 Jan 2000	0.17434	0.05308	0.15374	0.00245	3.29

Note: Data are preliminary.

Fecundity Hindcast Model (*FH*)

No independent estimate of survival of bay goby between age of entrainment and the egg stage was available in the literature.

Adult Equivalent Loss (*AEL*)

The total annual MLPP combined cycle entrainment of bay goby (March 1999 to March 2000) was used to estimate the number of equivalent adults theoretically lost to the population shown in Table 6-4. The estimated number of equivalent adults corresponding to the number of larvae that would have been entrained by the proposed MLPP combined-cycle intake was 1,045,588 (90 percent C.L. = 520,290 to 2,101,241).

Table 6-4. Annual Entrainment and *AEL* Estimates for Bay Goby *Lepidigobius lepidus*: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
152,755,000	643,860	0%

AEL Estimates for Bay Goby *Lepidogobius lepidus*

AEL Estimate	*AEL* Std. Error
1,045,588	443,627

Survival Early Larvae	Survival Late Larvae	Survival Early Juv.	Survival Juv. I	Survival Juv. II	Survival Juv. III	Survival Juv. IV	Survival Pre-Recruit
0.012775	1.0	1.0	1.0	1.0	1.0	1.0	0.535797

Upper 90% C.L.	Lower 90% C.L.
2,101,241	520,290

The uncertainty of our *AEL* estimate is most affected by the model parameters of early larval and early juvenile survivorship. Uncertainty in our entrainment estimates had relatively little effect on the confidence in the estimated *AEL*.

The bay goby has neither commercial nor recreational fishery value and there is little information on their ecological role in the community. There are no catch data that can be used to compare harvest mortality rates to entrainment mortality rates because of the absence of fishery data for this species. No estimates of stock size or density are available to convert *FH* or *AEL* entrainment effects into estimates of fractional loss, even assuming no compensatory mortality.

Results of *ETM* analyses using the two different source water volumes show that the power plant may annually entrain approximately 4 percent (Table 6-3a) or 21 percent (Table 6-3b) of the bay goby larvae from the MLPP source water. An independent estimate of *AEL* yields a predicted theoretical loss of 520,290 to 2,101,241 adults (males and females combined). The *ETM* estimate is not large enough to be of any important consequence to the local population of adult bay goby. The large estimate of *AEL* losses reflects a number of uncertainties in model input for life history parameters of this species and large source water concentrations in the vicinity of the power plant intake.

6.4 Blackeye Goby

The proportional entrainment values for the blackeye goby have varied an order of magnitude throughout the nine months of source water and entrainment studies as shown in Table 6-5. Changes in *PE* values ranging from zero to 0.04 (Table 6-5a) and from zero to 0.05 (Table 6-5b) correspond to fluctuations in the estimated of number of entrained blackeye goby. On several occasions the numbers of the blackeye gobies increased in the late evening entrainment cycles following the daytime source water sampling.

Empirical Transport Model (*ETM*)

The *ETM* values for blackeye goby as shown in Figure 6-5 are far below values that would represent consequential intake effects or any potential for long-term population declines. The *ETM* value, based on the Monterey Bay source water volume is 0.04 and 0.07 based a substitution of harbor/slough volume for Monterey Bay volume. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project's CWS on the area's blackeye goby.

Table 6-5a. Final *ETM* Output for Blackeye Goby *Coryphopterus nicholsi*. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.04318	0.03675	0.04318	0.04318

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.01042	0.00183	0.18997	0.00493	3.98
12 Jul 1999	18 Jun 1999	0.00403	0.00293	0.08754	0.00252	3.98
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.04002	0.00112	3.98
16 Sep 1999	13 Aug 1999	0.03964	0.05493	0.17607	0.00179	3.98
14 Oct 1999	17 Sep 1999	0.01304	0.01682	0.14578	0.00186	3.98
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.29972	0.00306	3.98
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.02504	0.00051	3.98
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.02382	0.00694	3.98
24 Feb 2000	21 Jan 2000	0.00868	0.00834	0.01203	0.00132	3.98

Table 6-5b. Final *ETM* Output for Blackeye Goby *Coryphopterus nicholsi. ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.07488	0.04756	0.07488	0.07488

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.01042	0.00183	0.18997	0.00493	3.98
12 Jul 1999	18 Jun 1999	0.03812	0.02762	0.08754	0.00252	3.98
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.04002	0.00112	3.98
16 Sep 1999	13 Aug 1999	0.03964	0.05493	0.17607	0.00179	3.98
14 Oct 1999	17 Sep 1999	0.04842	0.06081	0.14578	0.00186	3.98
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.29972	0.00306	3.98
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.02504	0.00051	3.98
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.02382	0.00694	3.98
24 Feb 2000	21 Jan 2000	0.05040	0.04763	0.01203	0.00132	3.98

Note: Data are preliminary.

Fecundity Hindcast Model (*FH*)

The total annual larval entrainment for blackeye goby was used to estimate the number of breeding females needed to produce the number of larvae entrained shown in Table 6-6. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained larvae is calculated assuming an age at maturation of 0.5 years and an average lifespan of 3.6 years. The number of adult females hindcast from the larvae entrained at MLPP combined-cycle intake was 1,825 (90 percent C.L. = 737 to 4,524).

Table 6-6. Annual Entrainment and *FH* Estimates for Blackeye Goby *Coryphopterus nicholsi*: March 1, 1999 through Feb 29, 2000.

Annual Entrainment	Annual Std. Error	CV
16,795,300	443,885	3%

Fecundity Hindcast (FH) Estimates for Blackeye Goby Coryphopterus nicholsi.

FH Estimate	*FH* Std. Error	Egg Survival	Yolk-Sac Survival	Larval Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
1,825	1,007	1.0	1.0	0.736313	8,062	3.6	0.5

Upper *FH* 90% C.L.	Lower *FH* 90% C.L.
4,524	737

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity, and larval survivorship, in that order.

Adult Equivalent Loss (*AEL*)

No independent estimate of survival of blackeye goby between age of entrainment adults was available in the literature. The methods used to estimate survival based on two goby species (cheekspot and shadow goby) are discussed in Section 4.

The total annual MLPP combined-cycle entrainment of blackeye goby (March 1999 to March 2000) was used to estimate the number of equivalent adults theoretically lost to the population shown in Table 6-7. The estimated number of equivalent adults corresponding to the number of larvae that would have been entrained by the proposed MLPP combined-cycle intake was 16,636 (90 percent C. L. = 8,277 to 33,436). We cannot assume that *AEL* is related to *FH* by a factor of two since blackeye goby are protogynous hermaphrodites.

Table 6-7. Annual Entrainment and *AEL* Estimates for Blackeye Goby *Coryphopterus nicholsi*: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
16,795,300	162,946	1%

AEL* Estimates for Blackeye Goby *Coryphopterus nicholsi

AEL Estimate	*AEL* Std. Error
16,636	7,060

Survival Early Larvae	Survival Late Larvae	Survival Early Juv.	Survival Juv. I	Survival Juv. II	Survival Juv. III	Survival Juv. IV	Survival Pre-Recruit
0.004254	1.0	1.0	1.0	1.0	1.0	1.0	0.232856

Upper 90% C.L.	Lower 90% C.L.
33,436	8,277

The uncertainty of our *AEL* estimate is most affected by the model parameters of early larval and early juvenile survivorship. Uncertainty in our entrainment estimates had relatively little effect on our confidence in the estimated *AEL*.

The blackeye goby has neither commercial nor recreational fishery value and there is little information on their ecological role in the community. There are no catch data that can be used to compare harvest mortality rates to entrainment mortality rates because of the absence of fishery data for this species. No estimates of stock size or density are available to convert entrainment effects estimated as *FH* or *AEL* losses into fractional population level losses, even assuming no compensatory mortality.

Results of *ETM* analyses using the two different source water volumes show that the power plant may annually entrain approximately 4 percent (Table 6-5a) or 7 percent (Table 6-5b) of the blackeye goby larvae from the MLPP source water. Fecundity hindcast estimates indicate that these values of *FH* may be equal to predicted losses of the reproductive output of about 737 to 4,524 adult females. An independent estimate of *AEL* yields a predicted loss of 8,277 to 33,436 adults (males and females combined).

6.5 Longjaw Mudsucker

The proportional entrainment values for the longjaw mudsucker have varied an order of magnitude throughout the nine months of source water and entrainment studies as shown in Table 6-8. The range of *PE* values from 0.002 to 0.17 in August 1999 (Table 6-8a) and from 0.005 to 0.17 (Table 6-8b), however, did not fluctuate with respect to the estimated number of entrained longjaw mudsucker larvae. In 5 of the 9 entrainment surveys that coincided with the source water surveys, the concentrations of longjaw mudsucker larvae increased in the evening entrainment cycles following the daytime source water sampling (Figure 4-30).

Empirical Transport Model (*ETM*)

The *ETM* values for longjaw mudsucker as shown in Table 6-8 are far below values that would represent consequential intake effects or any potential for long-term population declines. The *ETM* value, based the Monterey Bay source water volume is 0.05 and 0.09 when the harbor/slough source water volume is substituted for the Monterey Bay source water volume. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project's CWS on the area's populations of longjaw mudsucker.

Table 6-8a. Final *ETM* Output Longjaw Mudsucker *Gillichthys mirabilis*. *ETM* calculations based on **Monterey Bay volume 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.05199	0.01669	0.05199	0.05199

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00720	0.00520	0.08942	0.00320	3.42
12 Jul 1999	18 Jun 1999	0.00512	0.00513	0.07286	0.00067	3.42
12 Aug 1999	13 Jul 1999	0.17386	0.09087	0.05724	0.00233	3.42
16 Sep 1999	13 Aug 1999	0.02190	0.02665	0.09519	0.00246	3.42
14 Oct 1999	17 Sep 1999	0.00181	0.00183	0.10538	0.00236	3.42
18 Nov 1999	15 Oct 1999	0.00773	0.00269	0.27043	0.00323	3.42
29 Dec 1999	19 Nov 1999	0.00481	0.00299	0.17911	0.00380	3.42
20 Jan 2000	30 Dec 1999	0.00227	0.00239	0.08028	0.00362	3.42
24 Feb 2000	21 Jan 2000	0.01682	0.00629	0.05009	0.00354	3.42

Table 6-8b. Final *ETM* Output Longjaw Mudsucker *Gillichthys mirabilis*. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.08944	0.02159	0.08944	0.08944

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std .Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00720	0.00520	0.08942	0.00320	3.42
12 Jul 1999	18 Jun 1999	0.00512	0.00513	0.07286	0.00067	3.42
12 Aug 1999	13 Jul 1999	0.17386	0.09087	0.05724	0.00233	3.42
16 Sep 1999	13 Aug 1999	0.02190	0.02665	0.09519	0.00246	3.42
14 Oct 1999	17 Sep 1999	0.00603	0.00605	0.10538	0.00236	3.42
18 Nov 1999	15 Oct 1999	0.03655	0.01481	0.27043	0.00323	3.42
29 Dec 1999	19 Nov 1999	0.01142	0.00616	0.17911	0.00380	3.42
20 Jan 2000	30 Dec 1999	0.01807	0.01965	0.08028	0.00362	3.42
24 Feb 2000	21 Jan 2000	0.03209	0.00884	0.05009	0.00354	3.42

Note: Data are preliminary.

Fecundity Hindcast Model (*FH*)

The total annual larval entrainment for longjaw mudsucker (March 1999 to March 2000) was used to estimate the number of breeding females needed to produce the number of larvae entrained shown in Table 6-9. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained larvae is calculated assuming an age at maturation of 0.7 years and an average lifespan of 2.5 years. The number of adult females hindcast from the larvae entrained at MLPP combined-cycle intake was 497 (90 percent C.L. = 185 to 1,335).

Table 6-9. Annual Entrainment and *FH* Estimates for Longjaw Mudsucker *Gillichthys mirabilis*: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
8,009,110	241,784	3%

***FH* Estimates for Longjaw Mudsucker *Gillichthys mirabilis*.**

FH Estimate	*FH* Std. Error	Egg Survival	Yolk Sac Survival	Larval Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
497	298	1.0	1.0	0.454751	38,750	2.5	0.7

Upper *FH*	Lower *FH*
1,335	185

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity, and larval survivorship, in that order.

Adult Equivalent Loss (*AEL*)

No independent estimate of survival of longjaw mudsucker between age of entrainment and the adult stage was available in the literature.

The longjaw mudsucker goby provides a minor commercial bait fishery. There is no recreational fishery value. Little information exists on their ecological role in either the intertidal or subtidal marsh communities. Studies of their importance in trophic transfer and nutrient recycling in pickleweed (*Salicornia* spp.) marsh plants and amphipod (*Traskorchestia* spp.) populations in the Suisun Marsh have been undertaken recently by scientists from the Romberg Tiburon Research Center. There are no catch data from the Moss Landing study area that can be used to compare harvest mortality rates to entrainment mortality rates because of the absence of fishery data for this species. No estimates of stock size or density are available to convert entrainment effects expressed as *FH* or *AEL* losses into fractional population losses even assuming no compensatory mortality.

Results of *ETM* analyses using the two different source water volumes show that the power plant may annually entrain approximately 5 percent (Table 6-8a) or 9 percent (Table 6-8b) of the longjaw mudsucker larvae from the MLPP source water. Fecundity hindcast estimates indicate that these values of *FH* may be equal to predicted losses of the reproductive output of about 185 to 1,335 adult females.

6.6 Combtooth Blenny

The proportional entrainment values for the combtooth blenny have varied an order of magnitude throughout the nine months of source water and entrainment studies as shown in Table 6-10. The range of *PE* values from zero to 0.02 in August 1999 (Table 6-10a) and zero to 0.13 (Table 6-10b) however did not consistently correspond to the estimated number of entrained combtooth blenny larvae. Combtooth blenny were collected in 7 of the 9 entrainment surveys that coincided with source water surveys. The concentration of combtooth blenny larvae increased in 5 of these 7 surveys in the evening entrainment cycles following the daytime source water sampling (Figure 4-27).

Empirical Transport Model (*ETM*)

The *ETM* values for combtooth blennies as shown in Table 6-10 are below values that would represent consequential intake effects or any potential for long-term population declines. The *ETM* value, based on Monterey Bay source water volume is 0.11 and 0.18 when the harbor/slough water volume is used instead of the Monterey Bay source water volume. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project’s CWS on the area’s combtooth blennies.

Table 6-10a. Final *ETM* Output Unidentified Blennies *Hypsoblennius* spp. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.10993	0.05194	0.10993	0.10993

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00090	0.00091	0.02578	0.00202	7.81
12 Jul 1999	18 Jun 1999	0.00036	0.00016	0.06410	0.00156	7.81
12 Aug 1999	13 Jul 1999	0.01514	0.00717	0.18024	0.00247	7.81
16 Sep 1999	13 Aug 1999	0.02277	0.01542	0.49022	0.00252	7.81
14 Oct 1999	17 Sep 1999	0.00107	0.00078	0.17344	0.00126	7.81
18 Nov 1999	15 Oct 1999	0.01600	0.01696	0.06075	0.00066	7.81
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.00494	0.00017	7.81
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.00000	0.00000	7.81
24 Feb 2000	21 Jan 2000	0.01137	0.01598	0.00052	0.00026	7.81

Table 6-10b. Final *ETM* Output Unidentified Blennies *Hypsoblennius* spp. *ETM* calculations based **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3,
Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.18195	0.07861	0.18195	0.18195

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00357	0.00358	0.02578	0.00202	7.81
12 Jul 1999	18 Jun 1999	0.00346	0.00148	0.06410	0.00156	7.81
12 Aug 1999	13 Jul 1999	0.01514	0.00717	0.18024	0.00247	7.81
16 Sep 1999	13 Aug 1999	0.03645	0.02543	0.49022	0.00252	7.81
14 Oct 1999	17 Sep 1999	0.00354	0.00289	0.17344	0.00126	7.81
18 Nov 1999	15 Oct 1999	0.08682	0.07349	0.06075	0.00066	7.81
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.00494	0.00017	7.81
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.00000	0.00000	7.81
24 Feb 2000	21 Jan 2000	0.12954	0.17208	0.00052	0.00026	7.81

Note: Data are preliminary.

Fecundity Hindcast Model (*FH*)

The total annual larval entrainment for combtooth blenny was used to estimate the number of breeding females needed to produce the number of larvae entrained shown in Table 6-11. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained larvae is calculated assuming an age at maturation of 2.0 years and an average lifespan of 7.0 years. The number of adult females hindcast from the larvae entrained at MLPP combined-cycle intake was 9,086 (90 percent C L. = 3,335 to 24,752).

Table 6-11. Annual Entrainment and *FH* Estimates for Unidentified Blennies *Hypsoblennius* spp.: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
16,701,400	326,818	2%

***FH* Estimates for Unidentified Blennies *Hypsoblennius* spp.**

FH Estimate	*FH* Std. Error	Egg Survival	Yolk-Sac Survival	Larval Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
9,086	5,535	1.0	1.0	0.548721	1,340	7.0	2.0

Upper *FH* 90% C.L.	Lower *FH* 90% C.L.
24,752	3,335

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity, and larval survivorship, in that order.

Adult Equivalent Loss (*AEL*)

No independent estimate of survival of combtooth blenny between age of entrainment adults was available in the literature. The methods used to estimate survival are discussed in Section 4.

The total annual MLPP combined cycle entrainment of combtooth blenny (March 1999 to March 2000) was used to estimate the number of equivalent adults theoretically lost to the population as shown in Table 6-12. The estimated number of equivalent adults corresponding to the number of larvae that would have been entrained by the proposed MLPP combined-cycle intake was 10,247 (90 percent C.L. = 5,099 to 20,593). The uncertainty of our *AEL* estimate is most affected by the model parameters of early larval and early juvenile survivorship.

Table 6-12. Annual Entrainment and *AEL* Estimates for Unidentified Blennies *Hypsoblennius* spp.: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
16,701,400	85,044	1%

***AEL* Estimates for Unidentified Blennies *Hypsoblennius* spp.**

AEL Estimate	*AEL* Std. Error
10,247	4,348

Survival Early Larvae	Survival Late Larvae	Survival Early Juv.	Survival Juv. I	Survival Juv. II	Survival Juv. III	Survival Juv. IV	Survival Pre-Recruit
0.005708	1.0	1.0	1.0	1.0	1.0	1.0	0.107493

Upper 90% C.L.	Lower 90% C.L.
20,593	5,099

Uncertainty in our entrainment estimates had relatively little effect on the confidence of the estimated *AEL*.

The species of combtooth blenny in our study area and entrainment samples has not been positively identified (Section 4.5). Of the three species that it could possibly be, none support either a commercial or recreational fishery value and there is little information on their ecological role in the community. Even if we were certain of the species identification, there are no catch data that can be used to compare harvest mortality rates to entrainment mortality rates because of the absence of fishery data for any of the three possible species. No estimates of stock size or density are available for any of the three species to convert entrainment mortality effects estimated as *FH* and *AEL* values into an estimate fractional population losses.

Results of *ETM* analyses using the two different source water volumes show that the power plant may annually entrain approximately 11 percent (Table 6-10a) or 18 percent (Table 6-10b) of the combtooth blenny larvae from the MLPP source water. Fecundity hindcast estimates indicate that these values of *FH* may be equal to predicted losses of the reproductive output of about 3,335 to 24,752 adult females. An independent estimate of *AEL* yields a predicted loss of 5,099 to 20,593 adults (males and females combined). The significance of these losses to the local population of adult combtooth blenny is not known. The combtooth blenny, which is normally found further south, has recently invaded the harbor/slough area, possibly encouraged by El Nino currents or temperatures. If these effects were vital to the population success, it would seem reasonable that they would not have been able to colonize and grow to their present abundance.

6.7 Pacific Herring

Pacific herring are one of the only two species collected in entrainment surveys of commercial or recreational food value. The other species is white croaker which were only recently collected in the paired entrainment-source water surveys. The estimated number of entrained Pacific herring larvae was nearly twice the estimated source water number of Pacific herring larvae when they occurred on the single paired source water and entrainment sampling survey analyzed in the previous report. The resulting *PE* value of 0.52 (Table 6-13a and b) based on only two specimens probably reflects a mismatch between the source water location of hatching Pacific herring roe and source water sampling locations or depths. Pacific herring were again collected in the February 2000 surveys.

Empirical Transport Model (*ETM*)

The *ETM* value shown in Table 6-13 for Pacific herring based on the Monterey Bay source water volume is 0.13 and 0.13 when the harbor/slough volume is used in place of Monterey Bay source water volume.

Table 6-13a. Final *ETM* Output for Pacific Herring *Clupea pallasi*. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.12932	0.01608	0.12932	0.12932

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.52349	0.26787	0.12003	0.00700	7.55
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.05489	0.00141	7.55
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.00000	0.00000	7.55
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.02889	0.00074	7.55
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.00000	0.00000	7.55
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.04556	0.00117	7.55
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.04593	0.00841	7.55
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.02317	0.00604	7.55
24 Feb 2000	21 Jan 2000	0.00190	0.00088	0.68153	0.01129	7.55

Table 6-13b. Final *ETM* Output for Pacific Herring *Clupea pallasi*. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.13371	0.01677	0.13371	0.13371

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.52349	0.26787	0.12003	0.00700	7.55
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.05489	0.00141	7.55
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.00000	0.00000	7.55
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.02889	0.00074	7.55
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.00000	0.00000	7.55
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.04556	0.00117	7.55
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.04593	0.00841	7.55
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.02317	0.00604	7.55
24 Feb 2000	21 Jan 2000	0.00277	0.00132	0.68153	0.01129	7.55

Note: Data are preliminary.

Fecundity Hindcast Model (*FH*)

The total annual larval entrainment for Pacific herring (March 1999 to March 2000) was used to estimate the number of breeding females needed to produce the number of larvae entrained shown in Table 6-14. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained larvae is calculated assuming an age at maturation of 2.5 years and an average lifespan of 11 years. The number of adult females hindcast from the larvae entrained at MLPP combined-cycle intake was 235 (90 percent C.L. = 80 to 692).

Table 6-14. Annual Entrainment and *FH* Estimates for Pacific Herring *Clupea pallasi*: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
4,436,280	236,671	5%

FH Estimates for Pacific Herring *Clupea pallasi*

FH Estimate	*FH* Std. Error	Egg Survival	Yolk Sac Survival	Larval Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
235	154	0.3	1.0	0.221000	67,000	11.0	2.5

Upper *FH*	Lower *FH*
692	80

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity, and larval survivorship, in that order.

Adult Equivalent Loss (*AEL*)

The methods used to estimate Pacific herring survival are discussed in Section 4.

The total annual MLPP combined cycle entrainment of Pacific herring (March 1999 to March 2000) was used to estimate the number of equivalent adults theoretically lost to the population as shown in Table 6-15. The estimated number of equivalent adults corresponding to the number of larvae that would have been entrained by the proposed MLPP combined-cycle intake was 243 (90 percent C.L. = 121 to 488). The uncertainty of our *AEL* estimate is most affected by the model parameters of early larval and early juvenile survivorship. Uncertainty in our estimates of entrainment had relatively little effect on the uncertainty of the estimated *AEL*.

Table 6-15. Annual Entrainment and *AEL* Estimates for Pacific Herring *Clupea pallasi*: March, 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
4,436,280	88,934	2%

AEL* Estimates for Pacific Herring *Clupea pallasi

AEL Estimate	*AEL* Std. Error
243	103

Survival Early Larvae	Survival Late Larvae	Survival Early Juv.	Survival Juv. I	Survival Juv. II	Survival Juv. III	Survival Juv. IV	Survival Pre-Recruit
0.000405	1.0	1.0	1.0	1.0	1.0	1.0	0.135000

Upper 90% C.L.	Lower 90% C.L.
488	121

Results of *ETM* analyses using the two different source water volumes show that the power plant may annually entrain approximately 13 percent (Table 6-13a and b) of the Pacific herring larvae from the MLPP source water. Fecundity hindcast estimates indicate that these values of *FH* may be equal to predicted losses of the reproductive output of about 80 to 692 adult females. An independent estimate of *AEL* yields a predicted loss of 121 to 488 adults (males and females combined).

6.8 White Croaker

White croaker larvae have been collected only recently in the nine pairs of entrainment and source water surveys. White croaker, as discussed in Section 4, are one of only two fish species that have been collected in entrainment surveys that have commercial or recreational human food value. The other species is Pacific herring as previously discussed.

Empirical Transport Model (*ETM*)

The *ETM* value shown in Table 6-16 for white croaker based on the Monterey Bay source water volume is 0.016 and 0.13 when the harbor/slough volume is used in place of Monterey Bay source water volume. Results of the *ETM* analyses using the two different source water volumes show that the power plant may annually entrain approximately 2 percent (Table 6-16a) and 13 percent (Table 6-16b) of the white croaker larvae from the MLPP source water.

Table 6-16a. Final *ETM* Output for White Croaker *Genyonemus lineatus*. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{PM}$)	Std. Err.	+2 SE	-2 SE
0.01611	0.01546	0.01611	0.01611

Survey Date	*PE* Period Start	*PE* Estimate.	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	8.75
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	8.75
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.00000	0.00000	8.75
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.00000	0.00000	8.75
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.00000	0.00000	8.75
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.00730	0.00016	8.75
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.55402	0.01071	8.75
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.02142	0.00315	8.75
24 Feb 2000	21 Jan 2000	0.00449	0.00084	0.41725	0.01068	8.75

Table 6-16b. Final *ETM* Output White Croaker *Genyonemus lineatus*. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{PM}$)	Std. Err.	+2 SE	-2 SE
0.12912	0.02416	0.12912	0.12912

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	8.75
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.00000	0.00000	8.75
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.00000	0.00000	8.75
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.00000	0.00000	8.75
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.00730	0.00016	8.75
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.55402	0.01071	8.75
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.02142	0.00315	8.75
24 Feb 2000	21 Jan 2000	0.04144	0.00765	0.41725	0.01068	8.75

Note: Data are preliminary.

Fecundity Hindcast Model (*FH*)

The total annual larval entrainment for white croaker (March 1999 to March 2000) was used to estimate the number of breeding females needed to produce the number of larvae entrained shown in Table 6-17. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained larvae is calculated assuming an age at maturation of 2.0 years and an average lifespan of 12 years. The number of adult females hindcast from the larvae entrained at MLPP combined-cycle intake was 107 (90 percent C.L. = 43 to 270).

Table 6-17. Annual Entrainment and *FH* Estimates for White Croaker *Genyonemus lineatus*: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
8,627,070	404,930	5%

FH Estimates for White Croaker *Genyonemus lineatus*

FH Estimate	*FH* Std. Error	Egg Survival	Yolk Sac Survival	Larval Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
107	60	1.0	1.0	0.153478	105,000	12.0	2.0

Upper *FH*	Lower *FH*
270	43

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity and larval survivorship in that order.

Adult Equivalent Loss (*AEL*)

No independent estimate of survival of white croaker between age of entrainment and adult stage was available in the literature.

6.9 Pacific Staghorn Sculpin

The proportional entrainment values for Pacific staghorn sculpin have varied only a few tenths of a percent throughout the nine months of source water and entrainment studies as shown in Table 6-18. The range of values from a *PE* of zero to 0.009 in January and February 2000 (Table 6-18a) and from zero to 0.09 (Table 6-18b), however did not correspond consistently to the estimated number of entrained Pacific staghorn sculpin larvae.

Empirical Transport Model (*ETM*)

The *ETM* values for Pacific staghorn sculpin as shown in Table 6-18 are far below values that would represent consequential intake effects or any potential for long-term population declines. The *ETM* value based on Monterey Bay source water volume is 0.04 and 0.12 when the harbor/slough source water volume is used instead of Monterey Bay source water volume. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project's CWS on the area's Pacific staghorn sculpin.

Table 6-18a. Final *ETM* Output for Pacific Staghorn Sculpin *Leptocottus armatus*. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.03640	0.01982	0.03640	0.03640

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00128	0.00052	6.30
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	6.30
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.00000	0.00000	6.30
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.02418	0.00053	6.30
14 Oct 1999	17 Sep 1999	0.00738	0.00775	0.00930	0.00155	6.30
18 Nov 1999	15 Oct 1999	0.00765	0.00540	0.05360	0.00198	6.30
29 Dec 1999	19 Nov 1999	0.00176	0.00097	0.40993	0.00986	6.30
20 Jan 2000	30 Dec 1999	0.00926	0.00455	0.18391	0.01118	6.30
24 Feb 2000	21 Jan 2000	0.00945	0.00280	0.31779	0.01150	6.30

Table 6-18b. Final *ETM* Output for Pacific Staghorn Sculpin *Leptocottus armatus*. *ETM* Calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.11789	0.02993	0.11789	0.11789

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00128	0.00052	6.30
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	6.30
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.00000	0.00000	6.30
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.02418	0.00053	6.30
14 Oct 1999	17 Sep 1999	0.08797	0.09206	0.00930	0.00155	6.30
18 Nov 1999	15 Oct 1999	0.09091	0.06256	0.05360	0.00198	6.30
29 Dec 1999	19 Nov 1999	0.00490	0.00298	0.40993	0.00986	6.30
20 Jan 2000	30 Dec 1999	0.02791	0.01263	0.18391	0.01118	6.30
24 Feb 2000	21 Jan 2000	0.02512	0.00867	0.31779	0.01150	6.30

Note: Data are preliminary.

Fecundity Hindcast Model (*FH*)

No independent estimate of survival of Pacific staghorn sculpin between egg to entrainment age was available in the literature.

Adult Equivalent Loss (*AEL*)

No independent estimate of survival of Pacific staghorn sculpin between age of entrainment and the adult stage was available in the literature.

The Pacific staghorn sculpin sustains a minor commercial bait fishery in the Monterey area. The species has no recreational fishery value. Little information exists on their ecological role. No estimates of stock size or density are available to convert entrainment effects estimated as *FH* and *AEL* losses into estimates of fractional loss to adult populations.

Results of *ETM* analyses using the two different source water volumes show that the power plant may annually entrain approximately 4 percent (Table 6-18a) and 12 percent (Table 6-18b) of the Pacific staghorn sculpin larvae from the MLPP source water.

6.10 Hairy Rock Crab

The proportional entrainment values for hairy rock crab *Cancer jordani* have varied only a few tenths of a percent throughout the nine months of source water and entrainment studies as shown in Table 6-19. The *PE* values ranged from. zero to 0.00097 in September 1999 (Table 6 -19a) and from zero to 0.01 (Table 6-19b). Based on computed F_i values also shown in Table 6-19, the largest fractions of hairy rock crab megalops at risk occurred in September and October.

Empirical Transport Model (*ETM*)

The *ETM* values for hairy rock crab as shown in Table 6-19 are far below values that would represent consequential intake effects or any potential for long-term population declines. The *ETM* value based on Monterey Bay source water volume is 0.018 and 0.177 when the harbor/slough source water volume is used instead of Monterey Bay source water volume. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project's CWS on the area's hairy rock crab.

Table 6-19a. Final *ETM* Output Hairy Rock Crab. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.01842	0.06389	0.14621	-0.10936

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	45.00
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	45.00
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	45.00
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	45.00
14 Oct 1999	17 Sep 1999	0.00097	0.00098	0.39149	0.03525	45.00
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	45.00
29 Dec 1999	19 Nov 1999	0.00046	0.00047	0.07976	0.01700	45.00
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	45.00
24 Feb 2000	21 Jan 2000	0.00000	0.00000	0.04414	0.01213	45.00

Table 6-19b. Final *ETM* Output for Hairy Rock Crab. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.16722	0.13037	0.42797	-0.09352

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	45.00
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	45.00
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	45.00
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	45.00
14 Oct 1999	17 Sep 1999	0.01052	0.01057	0.39149	0.03525	45.00
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	45.00
29 Dec 1999	19 Nov 1999	0.00600	0.00613	0.07976	0.01700	45.00
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	45.00
24 Feb 2000	21 Jan 2000	0.00000	0.00000	0.04414	0.01213	45.00

Note: Data are preliminary.

Fecundity Hindcasting

The total annual larval entrainment for hairy rock crab was used to estimate the number of breeding females needed to produce the number of megalops entrained shown in Table 6-20. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalops is calculated assuming an age at maturation of 1.5 years and an average lifespan of 4.8 years. The number of adult females hindcast from the megalops entrained at MLPP combined-cycle intake was 1,039 (90 percent C.L. = 361 to 2,987).

Table 6-20. Annual Entrainment and *FH* Estimates for Hairy Rock Crab: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
1,740,210	275,839	16%

***FH* Estimates Hairy Rock Crab.**

FH Estimate	*FH* Std. Error	Egg Survival	Megalopal Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
1,039	667	1.0	0.000657	1,530,907	4.8	1.5

Upper *FH*	Lower *FH*
90% C.L.	90% C.L.
2,987	361

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity, and larval survivorship, in that order.

6.11 Yellow Rock Crab

Proportional entrainment values for yellow rock crab *Cancer anthonyi* could not be calculated because they were not collected in the paired source water survey and entrainment surveys. Based on computed F_i values listed in Table 6-21, the yellow rock crab megalops were most at risk to entrainment in October, more than twice the exposure of any other month.

Empirical Transport Model (*ETM*)

The lack of co-occurrence of entrainment and source water samples containing yellow crab megalops precludes the calculation of an *ETM* value. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project's CWS on the area's yellow rock crab.

Table 6-21a. Final *ETM* Output Yellow Rock Crab. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.00000	0.06263	0.12526	-0.12526

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	45.00
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	45.00
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	45.00
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	45.00
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.39149	0.03525	45.00
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	45.00
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.07976	0.01700	45.00
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	45.00
24 Feb 2000	21 Jan 2000	0.00000	0.00000	0.04414	0.01213	45.00

Table 6-21b. Final *ETM* Output for Yellow Rock Crab. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.00000	0.06263	0.12526	-0.12526

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	45.00
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	45.00
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	45.00
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	45.00
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.39149	0.03525	45.00
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	45.00
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.07976	0.01700	45.00
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	45.00
24 Feb 2000	21 Jan 2000	0.00000	0.00000	0.04414	0.01213	45.00

Note: Data are preliminary.

Fecundity Hindcasting

The total annual larval entrainment for yellow rock crab was used to estimate the number of breeding females needed to produce the number of megalops entrained shown in Table 6-22. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalops is calculated assuming an age at maturation of 1.5 years and an average lifespan of 4.8 years. The number of adult females hindcast from the megalops entrained at MLPP combined-cycle intake was 131 (90 percent C.L. = 46 to 374).

Table 6-22. Annual Entrainment and *FH* Estimates for Yellow Rock Crab: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
462,446	68,006	15%

***FH* Estimates.**

FH Estimate	*FH* Std. Error	Egg Survival	Megalopal Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
131	84	1.0	0.000817	2,600,000	4.8	1.5

Upper *FH*	Lower *FH*
90% C.L.	90% C.L.
374	46

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity, and larval survivorship, in that order.

6.12 Brown Rock Crab

Proportional entrainment values for brown rock crab *Cancer antennarius* could not be calculated because they were not collected in the paired source water and daytime entrainment surveys. Based on computed F_i values listed in Table 6-23, brown rock crab megalops were most at risk to entrainment in October.

Empirical Transport Model (*ETM*)

The lack of co-occurrence of entrainment and source samples containing brown rock crab megalops precludes the calculation of an *ETM* value. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project's CWS on the area's brown rock crab.

Table 6-23a. Final *ETM* Output for Brown Rock Crab. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{PM}$)	Std. Err.	+2 SE	-2 SE
0.00000	0.06263	0.12526	-0.12526

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	43.30
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	43.30
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	43.30
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	43.30
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.39149	0.03525	43.30
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	43.30
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.07976	0.01700	43.30
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	43.30
24 Feb 2000	21 Jan 2000	0.00000	0.00000	0.04414	0.01213	43.30

Table 6-23b. Final *ETM* Output for Brown Rock Crab. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{PM}$)	Std. Err.	+2 SE	-2 SE
0.00000	0.06263	0.12526	-0.12526

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	43.30
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	43.30
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	43.30
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	43.30
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.39149	0.03525	43.30
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	43.30
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.07976	0.01700	43.30
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	43.30
24 Feb 2000	21 Jan 2000	0.00000	0.00000	0.04414	0.01213	43.30

Note: Data are preliminary.

Fecundity Hindcasting

The total annual larval entrainment for brown rock crab was used to estimate the number of breeding females needed to produce the number of megalops entrained shown in Table 6-24. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalops is calculated assuming an age at maturation of 1.5 years and an average lifespan of 5.5 years. The number of adult females hindcast from the megalops entrained at MLPP combined-cycle intake was 209 (90 percent C.L. = 71 to 612).

Table 6-24. Annual Entrainment and *FH* Estimates for Brown Rock Crab: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
784,554	198,934	25%

***FH* Estimates.**

FH Estimate	*FH* Std. Error	Egg Survival	Megalopal Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
209	137	1.0	0.001069	1,756,450	5.5	1.5

Upper *FH*	Lower *FH*
90% C.L.	90% C.L.
612	71

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity, and larval survivorship, in that order.

6.13 Dungeness Crab

ETM calculations were not done for dungeness crab *Cancer magister*. There were no dungeness crab megalops collected in the source water surveys from June 1999 through February 2000. They were collected in entrainment samples from the new combined-cycle units intake before the source water survey began. We may collect dungeness crab megalops in the March and April 2000 surveys.

Fecundity Hindcasting

The total annual larval entrainment for dungeness crab was used to estimate the number of breeding females needed to produce the number of megalops entrained shown in Table 6-25. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalops is calculated assuming an age at maturation of 2.0 years and an average lifespan of 6.0 years. The number of adult females hindcast from the megalops entrained at MLPP combined-cycle intake was 167 (90 percent C.L. = 56 to 496).

Table 6-25. Annual Entrainment and *FH* Estimates for Dungeness Crab: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
335,180	59,594	18%

***FH* Estimates.**

FH Estimate	*FH* Std. Error	Egg Survival	Megalopal Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
167	110	1.0	0.000802	1,250,000	6.0	2.0

Upper *FH*	Lower *FH*
90% C.L.	90% C.L.
496	56

6.14 Red Rock Crab

The proportional entrainment value of 0.95 (Table 6-26a and b) for red rock crab *Cancer productus* was computed from the single occasion when its megalops were collected in both entrainment and source water samples. The computed F_i values listed in Table 6-26 indicate that red rock crab are at risk of entrainment from August to February, with peak exposure in October.

Empirical Transport Model (*ETM*)

The *ETM* values for red rock crab as shown in Table 6-26 are far below values that would represent consequential intake effects or any potential for long-term population declines. The *ETM* value based on Monterey Bay source water volume is 0.04 and also 0.04 when the harbor/slough source water volume is used instead of Monterey Bay source water volume. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project's CWS on the area's red rock crab.

Table 6-26a. Final *ETM* Output for Red Rock Crab. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{PM}$)	Std. Err.	+2 SE	-2 SE
0.04414	0.06144	0.16702	-0.07875

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_I	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	97.00
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	97.00
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	97.00
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	97.00
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.39149	0.03525	97.00
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	97.00
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.07976	0.01700	97.00
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	97.00
24 Feb 2000	21 Jan 2000	0.95023	1.34383	0.04414	0.01213	97.00

Table 6-26b. Final *ETM* Output for Red Rock Crab. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{PM}$)	Std. Err.	+2 SE	-2 SE
0.04414	0.06144	0.16702	-0.07875

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	97.00
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	97.00
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	97.00
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	97.00
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.39149	0.03525	97.00
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	97.00
29 Dec 1999	19 Nov 1999	0.00000	0.00000	0.07976	0.01700	97.00
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	97.00
24 Feb 2000	21 Jan 2000	0.95023	1.34383	0.04414	0.01213	97.00

Note: Data are preliminary.

Fecundity Hindcasting

The total annual megalopal entrainment for red rock crab was used to estimate the number of breeding females needed to produce the number of megalops entrained shown in Table 6-27. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalops is calculated assuming an age at maturation of 1.5 years and an average lifespan of 4.8 years. The number of adult females hindcast from the megalops entrained at MLPP combined-cycle intake was 60 (90 percent C.L. = 20 to 181).

Table 6-27. Annual Entrainment and *FH* Estimates for Red Rock Crab: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
246,363	64,237	26%

***FH* Estimates.**

FH Estimate	*FH* Std. Error	Egg Survival	Megalopal Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
60	40	1.0	0.001658	1,492,500	4.8	1.5

Upper *FH*	Lower *FH*
90% C.L.	90% C.L.
181	20

6.15 Slender Rock Crab

The proportional entrainment values for slender rock crab *Cancer gracilis* is from a single survey in December, when they were collected in both entrainment and source samples. The *PE* values of 0.009 (Table 6-28a) and 0.11 (Table 6-28 b) were used to calculate the *ETM* values in Table 6-28. However, a single estimated proportional entrainment value does provide a robust *ETM* estimate.

Empirical Transport Model (*ETM*)

The *ETM* values for slender rock crab as shown in Table 6-28 are far below values that would represent consequential intake effects or any potential for long-term population declines. The *ETM* value based on Monterey Bay source water volume is 0.03 and 0.08 when the harbor/slough source water volume is used instead of Monterey Bay source water volume. The MLPP entrainment impact evaluation gives no indication of any potential impacts of the new combined-cycle project's CWS on the area's slender rock crab.

Table 6-28a. Final *ETM* Output Slender Rock Crab. *ETM* calculations based on **Monterey Bay volume = 275,000,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.02531	0.06662	0.15855	-0.10792

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	41.60
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	41.60
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	41.60
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	41.60
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.39149	0.03525	41.60
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	41.60
29 Dec 1999	19 Nov 1999	0.00914	0.01132	0.07976	0.01700	41.60
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	41.60
24 Feb 2000	21 Jan 2000	0.00000	0.00000	0.04414	0.01213	41.60

Table 6-28b. Final *ETM* Output for Slender Rock Crab. *ETM* calculations based on **Monterey Bay volume = 21,100,000 m^3**, Elkhorn Slough volume = 21,100,000 m^3, Moss Landing Harbor volume = 2,200,000 m^3.

ETM Estimate ($\hat{P}M$)	Std. Err.	+2 SE	-2 SE
0.07903	0.06044	0.19990	-0.04184

Survey Date	*PE* Period Start	*PE* Estimate	*PE* Std. Err.	F_i	F_i Std. Err.	Larval Duration
17 Jun 1999	18 May 1999	0.00000	0.00000	0.00000	0.00000	41.60
12 Jul 1999	18 Jun 1999	0.00000	0.00000	0.00000	0.00000	41.60
12 Aug 1999	13 Jul 1999	0.00000	0.00000	0.01544	0.00549	41.60
16 Sep 1999	13 Aug 1999	0.00000	0.00000	0.16551	0.03712	41.60
14 Oct 1999	17 Sep 1999	0.00000	0.00000	0.39149	0.03525	41.60
18 Nov 1999	15 Oct 1999	0.00000	0.00000	0.13819	0.01741	41.60
29 Dec 1999	19 Nov 1999	0.10672	0.12820	0.07976	0.01700	41.60
20 Jan 2000	30 Dec 1999	0.00000	0.00000	0.16548	0.02310	41.60
24 Feb 2000	21 Jan 2000	0.00000	0.00000	0.04414	0.01213	41.60

Note: Data are preliminary.

Fecundity Hindcasting

The total annual larval entrainment for slender rock crab was used to estimate the number of breeding females needed to produce the number of larvae entrained shown in Table 6-29. The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalops is calculated assuming an age at maturation of 1.0 year and an average lifespan of 3.0 years. The number of adult females hindcast from the megalops entrained at MLPP combined-cycle intake was 239 (90 percent C.L. = 77 to 740).

Table 6-29 Annual Entrainment and *FH* Estimates for Slender Rock Crab: March 1, 1999 through February 29, 2000.

Annual Entrainment	Annual Std. Error	CV
185,757	47,909	26%

***FH* Estimates Slender Rock Crab.**

FH Estimate	*FH* Std. Error	Egg Survival	Megalopal Survival	Eggs per Year	Average Lifespan (yrs)	Age at Maturation
239	164	1.0	0.001398	555,583	3.0	1.0

Upper *FH*	Lower *FH*
90% C.L.	90% C.L.
740	77

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the uncertainty of the model parameters of average lifespan, fecundity, and larval survivorship, in that order.

6.16 Summary of Entrainment Effects

The concentrations of fish and crab larvae collected at the new combined-cycle intake were used to estimate entrainment losses by extrapolating to both a representative numbers of adults and by the fractional larval entrainment loss to the adult population. Three independent models, fecundity hindcast (*FH*), adult equivalent loss (*AEL*) and empirical transport model (*ETM*), were employed in calculating entrainment losses. Results from the three models are summarized where applicable by species of fishes and crabs in Table 6-30a and b, respectively. Estimated losses of adult bay goby and combtooth blennies, the highest losses identified in our assessment of entrainment effects, indicate a potential for local population level impacts. However these estimated theoretical losses are based on *AEL* and *FH* modeling results using generalized larval mortality information that may or may not accurately represent the specific species' larval survival rates. In the case of the blenny, we are uncertain which of possibly three combtooth blenny species we have collected. Our study's modeling results, as summarized in Table 6-30, generally demonstrate both low levels of entrainment effects and in theory commensurately low potentials for adverse population level impacts.

Information about the size of the species' adult fish populations is required to convert the *FH, AEL,* and *ETM* estimates into comparable units of fishes depends on data describing. However, the majority of taxa found in our study are not commercially or recreationally harvested. The absence of a population assessment or any fishery data for this species we could not provide any context for the estimates. For example, egg and larval mortality data for blackeye goby allowed the application of multiple assessment approaches, but because the species is not harvested or monitored at the population level the losses cannot be compared to any standing stock of blackeye goby.

For those species with both *FH* and *AEL* estimated losses, the model results can be compared directly using the relationship *AEL* = 2*FH*. This conversion requires that ages of *AEL* and *FH* individuals are equal in a 50:50 sex ratio. Results for abundant taxa that were in close agreement with the relationship 2*FH* = *AEL* provide some assurance that the parameters used in the models were representative for the study area populations. They also increase confidence that the assessments of effects on these populations are reasonably accurate. Two examples were white croaker and the Pacific herring.

For the abundant taxa without available life history information, length measurements of larvae from the entrainment samples provided some insight into their larval life history and ecology. The length ranges for most of the entrained abundant larval fish taxa indicate that their exposure to entrainment occurs over a relatively short time period during their development. Average lengths were small demonstrating that they were exposed to entrainment for a brief period during their larval development. The lack of these later developmental stages indicates larval behavior that removes them from risk of entrainment as they develop (e.g., settlement to benthic habitats or migration into deeper areas away from the intake).

Abundant larval taxa that are not commercially or recreationally harvested are primarily small bay and slough fishes. As might be expected due to the shallow water, shoreline intake location, several of these taxa are entrained in relatively high numbers, resulting in large *AEL* and *FH* estimates (Table 6-30). For example, losses of approximately 300, 000 unidentified gobies and 1,450,000 bay goby were estimated using the *FH* and *AEL* models, respectively. However *ETM* values for the two species were relatively small (unidentified gobies = 0.026 [Table 6-1a] and 0.214 [Table 6-1b] and bay goby = 0.039 [Table 6-3a] and 0.106 [Table 6-3b]).

Results from the present study indicate effects on commercially and recreationally harvested species with pelagic distributions such as Pacific herring and white croaker are minimal. For cases where we were able to apply all three assessment approaches, the effects detected were relatively small, appeared to be localized, and thus could not affect the overall adult populations. There was very little available information on the demography of our most abundant taxa that were not commercially or recreationally important. This lack of life history information limited the application of assessment models to the *ETM*.

In summary, it is unlikely that populations of fishes and crabs will to be adversely affected by the new combined-cycle cooling water intake. Some are commercially important taxa with pelagic eggs and widespread populations (e.g., white croaker). Their assessments resulted in either low estimated larval mortalities or small numbers of adult losses to their populations. Other widespread species also had low numbers of estimated adult equivalent losses to their populations and low estimated larval mortality, with populations that are distributed well beyond the zone of influence of MLPP, such as Pacific herring and Pacific staghorn sculpin.

The models used for entrainment assessment considered functions critical to the life history of the abundant taxa of fishes and crabs. These models were applied both at the point of entrainment for estimating the numbers of individuals entrained and also in the adjacent Elkhorn Slough, Moss Landing Harbor, and Monterey Bay areas for estimating the population of inference. The area around MLPP includes nursery and feeding areas for many species of our abundant taxa, particularly goby species. These areas also extend away from MLPP zone of influence. In the case of Pacific herring the center of spawning biomass is located well north of Monterey Bay. Length measurements of larvae indicate that most of the abundant taxa were produced locally and thus are exposed to entrainment for a relatively short period of time during their larval development. These results indicate that entrainment effects appear to be limited to localized effects on bay and slough species. Therefore, the potential for entrainment damage to commercially or recreationally source water body species is low.

Table 6-30. Summary of Estimated MLPP New Combined-cycle Entrainment Effects for Abundant Fishes and Cancer Crabs Based on *ETM*, *FH*, and *AEL* Models Using Entrainment and Source Water Larval Concentrations and Monterey Bay, Moss Landing Harbor, and Elkhorn Slough Volumes (March 1999–February 2000).

(a) Fishes

	Total Entrainment	*FH*	*AEL*	*ETM*[(a)]	*ETM*[(b)]
Unidentified gobies	2.7 x 10^8	300,006	*	0.026	0.107
Bay goby	1.5 x 10^8	*	1,045,588	0.039	0.214
Blackeye goby	1.7 x 10^7	1,825	16,636	0.043	0.075
Longjaw mudsucker	8.0 x 10^6	497	*	0.052	0.089
Hypsoblennius spp.	1.7 x 10^7	9,086	10,247	0.111	0.182
Pacific herring	4.4 x 10^6	235	243	0.129	0.134
White croaker	8.6 x 10^6	107	*	0.016	0.129
Pacific staghorn sculpin	*	*	*	0.036	0.118

	FH	Total Entrainment	Egg Survival	Yolk-sac Survival	Larvae Survival	Eggs/year
Unidentified gobies	300,006	2.7 x 10^8	*	*	0.68	1,750
Bay goby	*	1.5 x 10^8	*	*	*	*
Blackeye goby	1,825	1.7 x 10^7	*	*	0.74	8,062
Longjaw mudsucker	497	8.0 x 10^6	*	*	0.45	38,750
Hypsoblennius spp.	9,086	1.7 x 10^7	*	*	0.55	1,340
Pacific herring	235	4.4 x 10^6	0.3	*	0.22	67,000
White croaker	107	8.6 x 10^6	*	*	0.15	105,000
Pacific staghorn sculpin	*	1.0 x 10^7	*	*	*	*

	AEL	Total Entrainment	Average Lifespan (years)	Age at Maturation (years)	Early Larvae	Late Larvae through Juvenile IV	Pre-Recruit
Unidentified gobies	*	2.7 x 10^8	2.5	1	*	*	*
Bay goby	1,045,588	1.5 x 10^8	*	*	0.013	*	0.536
Blackeye goby	16,636	1.7 x 10^7	3.6	0.5	0.004	*	0.233
Longjaw mudsucker	*	8.0 x 10^6	2.5	0.7	*	*	*
Hypsoblennius spp.	10,247	1.7 x 10^7	7	2	0.006	*	0.107
Pacific herring	243	4.4 x 10^6	11	2.5	0.0004	*	0.135
White croaker	*	8.6 x 10^6	12	2	*	*	*
Pacific staghorn sculpin	*	1.0 x 10^7	*	*	*	*	*

*Unavailable information or value that could not be computed.

(a) *ETM* values calculated using source water volumes 275, 21, and 2.2 m^3 x 10^6.

(b) *ETM* values calculated using source water volumes 22, 21, and 2.2 m^3 x 10^6.

Table 6-30 (continued). Summary of Estimated MLPP New Combined-cycle Entrainment Effects for Abundant Fishes and Cancer Crabs Based on *ETM*, *FH*, and *AEL* Models Using Entrainment and Source Water Larval Concentrations and Monterey Bay, Moss Landing Harbor, and Elkhorn Slough Volumes (March 1999–February 2000).

(b) Cancer Crabs

	Total Entrainment	*FH*	*ETM*[(a)]	*ETM*[(b)]
Hairy rock crab	1.7 x 10^6	1,039	0.018	0.167
Yellow rock crab	0.5 x 10^6	131	*	*
Brown rock crab	0.8 x 10^6	209	*	*
Dungeness crab	0.3 x 10^6	167	*	*
Red rock crab	0.2 x 10^6	60	0.044	0.044
Slender crab	0.2 x 10^6	239	0.025	0.079

	Total Entrainment	*FH*	Egg Survival	Megalopal Survival	Eggs/year	Average Lifespan (years)	Age at Maturation (years)
Hairy rock crab	1.7 x 10^6	1,039	1.0	0.000657	1,530,907	4.8	1.5
Yellow rock crab	0.5 x 10^6	131	1.0	0.000817	2,600,000	4.8	1.5
Brown rock crab	0.8 x 10^6	209	1.0	0.001069	1,756,450	5.5	1.5
Dungeness crab	0.3 x 10^6	167	1.0	0.000802	1,250,000	6.0	2.0
Red rock crab	0.2 x 10^6	60	1.0	0.001658	1,492,500	4.8	1.5
Slender crab	0.2 x 10^6	239	1.0	0.001398	555,583	3	1

*Unavailable information or value that could not be computed.

(a) *ETM* values calculated using source water volumes 275, 21, and 2.2 m^3 x 10^6.

(b) *ETM* values calculated using source water volumes 22, 21, and 2.2 m^3 x 10^6.

6.17 Impingement Effects Assessment

The combined-cycle intake modernization project is expected to significantly reduce historic impingement rates by modernization of the existing Units 1 through 5 intake. The existing intake structure will be modified to eliminate its 350-foot forebay tunnel. Based on intake structure design guidance (EPA, 1976) long tunnels or channels in front of a facility's intake screens entrap fishes and invertebrates and should be avoided whenever possible. The previous (1979 – 1980) MLPP impingement rates reviewed in Section 5 showed that impingement rates measured at Units 1 through 5 intake were significantly higher that at Units 6 and 7 intake, particularly in the rate of crab impingement. This higher impingement rate is attributable in a large part to the entrapment effect of the Units 1 through 5 intake's extraordinarily long forebay. It is therefore reasonable to forecast that with the elimination of the existing intake forebay (making the intake flush to the shoreline) that the modernized intake's impingement rate would be equivalent to the impingement rate observed at Units 6 and 7's shoreline intake.

The benefit, reduction of impingement losses, can be estimated by using the historical impingement rates described in Section 5. On this basis, the effect of moving the intake forebay and screens to the shoreline would have reduced the total annual impingement of fishes at Units 1 through 5 from 2,875/day to 1,657/day and the total annual impingement of crabs from 236/day to 139/day. In addition to this level of reduction of impingement losses achieved by moving the combined-cycle intake to the shoreline location, the modernized combined-cycle units will withdraw 44 percent less water than the existing Units 1 through 5 pumps. Lower volumes of cooling water withdrawal are expected to further reduce the potential for impingement by further lowering the combined-cycle's impingement effects. The relationship between rates of intake water withdrawal and rates of impingement is not strictly a direct relationship, due to the presence or absence of debris effects on impingement rates. A general relationship holds that if less water is withdrawn the potential for the impingement of organisms and debris will be lower. We have not attempted to quantify the expected benefits of reduced combined-cycle intake flows on impingement rates of the existing facility, but believe they represent a potential for significant reductions in impingement rates with the new combined-cycle units.

New traveling screens that are planned for the combined-cycle modernized intake facility may also contribute to lower impingement rates. The installation of continuous-belt, incline screens is being investigated as a means to reduce intake screen maintenance and improve reliability.
A biological benefit of the new screen designs, is that with fewer structural members, the effective screen area is increased and through-screen velocities reduced accordingly. The screens are installed at an angle, compared to the more common vertically installed screens. The angle of the screen allows gravity to keep debris on the screen surface as it clears the water and is lifted to

the spray nozzles and sluiceways. The angle of screen inclination also serves to increase the effective screen surface area and lower through-screen velocities from approximately 2.0 fps to 0.8 fps (see Table 2-1). At intake facilities where fish return systems are employed, lower through-screen velocities improve the survival of the impinged organisms that are returned. Though this factor does not apply to the MLPP combined-cycle intake, lower through screen velocities should in theory make it easier for small fishes to navigate in and out of the shoreline intake structure. However, the projected combined-cycle intake approach velocity of 0.5 fps is well below the swimming burst speeds of most of the study area's fishes. Lower through-screen velocities represent a small, but positive potential for lower impingement rates with the new combined-cycle units.

7.0 EVALUATION OF ALTERNATIVE INTAKE TECHNOLOGIES

The purpose of this section is to evaluate alternative intake technologies for the combined-cycle (formerly Units 1 through 5) cooling water intake structure, which will be modified to serve the proposed combined-cycle (CC) units at the Moss Landing Power Plant. Though the entrainment and impingement effects are negligible at this point of the current study, alternative intake technologies were evaluated for their potential to further reduce biological losses. The feasibility and cost-effectiveness for each alternative intake technology was evaluated for the Moss Landing Power Plant combined-cycle units on a site-specific basis. A hierarchical evaluation system is used to assess which alternative intake technologies would reduce biological losses and could be feasible for application to the cooling water system of the plant. Alternative intake technologies were evaluated on the basis of the following four criteria:

1. the alternative technology is available and proven (i.e., it has demonstrated operability and reliability at a cooling water intake having a similar size and environmental setting to that at the MLPP),
2. implementation of the alternative technology will result in a reduction in the loss of aquatic organisms from the present operating conditions described in Section 2,
3. implementation of the alternative technology is feasible at the MLPP site, based on site-specific considerations of engineering, operations, and reliability, and
4. the total economic cost of the alternative technology is proportionate to the environmental benefits anticipated.

These criteria were applied to all alternative intake technologies that were considered to be available and proven for application at the plant (Criterion 1) and were, therefore, subjected to a biological evaluation (Criterion 2). Feasibility analyses (Criteria 3 and 4) were carried out for alternatives that would reduce biological losses. The section ends with a discussion of, and judgment as to, the best intake technology available for the new combined-cycle units.

Evaluation of whether an intake technology is available and will minimize impacts requires site-specific analyses, which are presented in this section. The design and operation of the cooling water systems for the new combined-cycle units are described in Section 2, along with a discussion of the physical and biological characteristics of the source waterbody. Sections 3 through 5 present information characterizing entrainment and impingement at the plant. This background information provides the site-specific framework necessary for evaluating the potential biological effectiveness and engineering feasibility of each intake technology considered.

7.1 First-level Evaluation — Are the Technologies Proven and Available?

Certain intake technologies and alternate intake locations were determined to be proven and available for consideration for the new CC units (Table 7-1). These include offshore and onshore intake locations and configurations, a once-through cooling water system, and behavioral barriers such as light, sound, bubble screens, and velocity caps. Fish diversion systems, such as louvers and angled screens, have been used at cooling water intake structures (CWIS) and can be considered for use by the CC units. Physical barriers, such as drum screens, center-flow screens, and vertical traveling screens, are also appropriate for further consideration. Fish collection and return systems, including modified traveling screens and fish pump systems are available considerations.

Although not commonly used as intake technology, closed-cycle cooling systems, such as salt water cooling towers and air cooled condensers, have been demonstrated in power plant applications.

Table 7-1. Operational Feasibility of Intake Technologies and Operational Alternatives Considered for the Proposed MLPP Combined-cycle Units.

Intake Technologies	Demonstrated Proven and Available	Not Demonstrated Proven and Available
Intake Location	Offshore	
	Onshore	
Intake Configuration	Shoreline	
	Recessed	
Behavioral Barrier	Light	Velocity gradient
	Sound	Electrical barrier
	Air bubble curtain	
	Velocity cap (applicable to offshore intake location only)	Chemicals
		Magnetic field
		Chains and cables
Diversion Systems	Louvers	
	Angled Screens	
Physical Barrier		Media filter
	Centerflow screen	Porous dike
	Vertical Traveling screen	Radial Well
	Barrier net	Stationary screen
	Gunderboom	Horizontal traveling screen
		Caisson
		Drum screens
		Cylindrical, wedge-wire screens
Fish Collection, Removal, and Conveyance Systems	Modified traveling water screens	
	Gravity sluiceway	
	Fish pump	
Operational and Flow-reduction Alternatives		
Maintenance and Operational Modifications	Closed-cycle cooling	
	Cooling water pump flow reduction	
	Dredging	
	Seasonal Flow Reduction	
	Alternate biofouling control	

Operational and flow-reduction alternatives, such as closed-cycle cooling, seasonal energy curtailment resulting in flow reductions, cooling system structural modifications, temperature regulation, maintenance dredging of the intake area, and cooling water pump flow reduction are also regarded as proven and available technologies. Other alternative technologies failed to satisfy the first evaluation criterion, and hence are not considered further in the analysis. Those technologies and operational alternatives are discussed briefly in the following discussion.

7.1.1 Behavioral Barriers

Devices such as velocity gradients, electric barriers, magnetic fields, water jet curtains, hanging chains, visual cues and chemicals have been suggested, and in some cases evaluated, as fish protection measures. However, no practical applications of these devices have been developed and they are not considered available technologies for application at CWIS (Taft, 1999). Of the remaining behavioral barriers, lights, sound and air bubble curtains are carried forward to the next level of evaluation.

7.1.2 Diversion Systems

Louvers have been used effectively at several large agricultural water diversions and hydroelectric installations. Only one power plant cooling water intake incorporates louvers. However, no biological evaluations of this installation have been performed. Most of the louver applications to date have been with migratory species in riverine environments. Therefore, the ability of this alternative to protect species commonly impinged at CWIS is largely unknown. Further, due to the large spacings between louver slats, louver systems do not provide a positive barrier either to early life stages of fishes or to debris that could block the condenser tube system and lead to reduced operating reliability and increased maintenance. Therefore, traveling water screens are required downstream of louvers for CWIS applications. Future consideration of louver systems for protecting fishes at cooling water intakes may be warranted but would require extensive large-scale engineering feasibility and biological evaluations.

7.1.3 Physical Barriers

Media filters, such as rapid sand filters, porous dikes, and radial well intakes, have never been used to provide power plant cooling water from a marine source. Prototype tests have been conducted that have identified debris accumulation, biofouling, and sedimentation as major constraints in the application of media filters in the marine environment. Results of laboratory and small-scale pilot studies have indicated that porous dikes might be effective in preventing passage of juvenile and adult fishes. However, entrainable organisms will generally be trapped in the porous medium or entrained into the pump flow.

In the absence of demonstrated performance capabilities and operational reliability in a once-through power plant cooling water system, media filters are not considered to be an available technology for the new combined-cycle units.

To date, large-scale CWIS applications of wedge-wire screens have been limited to two power plants. These screens have been biologically effective in preventing entrainment and impingement of larger fishes and have not caused unusual maintenance problems. This technology can be considered for application at CWIS. However, there are major concerns with clogging potential and biogrowth. Since the only two large CWIS to employ wedge-wire screens to date use 6.4 and 10 mm slot openings, the potential for clogging and fouling that would exist with slot sizes as small as 0.5 mm, as would be required for protection of entrainable life stages, is unknown. In general, consideration of wedge-wire screens with small slot dimensions for CWIS application should include *in situ* prototype scale studies to determine potential biological effectiveness and identify the ability to control clogging and fouling in a way that does not impact plant operation. Assuming that biofouling can be controlled, the only environment in which use of cylindrical wedge-wire screens may not be practicable is one without an ambient cross-current to carry passive organisms and backflushed debris away.

Stationary screens have had little application at CWIS. No information is available on recent advances or installations of flat-panel screens for use as a fish barrier. Except on small volume intakes, it is expected that maintaining fixed screens in a clean condition, and thereby minimizing head loss, will preclude use of these screens.

The traveling water screen is a standard feature at most CWIS. The ability of traveling screens to act as a barrier to fishes while not resulting in impingement is dependent on many site-specific factors, such as the size of fish, location of the screens, and presence of escape routes. It is considered advantageous to locate screens close to the shoreline at the point of water withdrawal, as proposed for the new CC units CWIS. Traveling screens, as barrier devices, cannot be considered for protection of early life stages or aquatic organisms that have little or no motility.

The horizontal traveling screen concept combines elements of diversion and collection devices and might have been an effective fish protection system if engineering problems could have been overcome. Unfortunately, years of design, research, and development efforts at two sites did not result in a screen that could operate reliably, even for relatively short periods of time. There has been no additional work on this technology and it is not considered available for application at CWIS.

Similarly, while rotary drum screens are often mentioned as technologies for protecting fishes at CWIS, no evidence of applications exists. Drum screens have been used at irrigation and hydroelectric facilities but, even in these applications, the screens are limited by the requirement for maintaining constant water elevations. Drums screens are not considered to be biologically effective, based on the limited data available (Eicher, 1974), and are not expected to reduce the numbers of organisms entrained or impinged at the plant's cooling water intake structures. There is no information available to suggest that survival of organisms impinged on drum screens would be significantly different from impingement survival on conventional vertical traveling screens. In the absence of any predicted biological advantages, drum screens are not considered to be an acceptable alternative intake technology applicable to the new combined-cycle units.

7.2 Second-Level Evaluation — Will The Technology Result In Biological Benefits?

Each technology and operational alternative that satisfied the proven and available criterion in the first-level evaluation (Table 7-1) was further investigated to determine whether it would reduce the entrainment and impingement losses reported in Sections 4 and 5. Relevant results of the evaluation are integrated in this section.

7.2.1 Closed-Cycle Cooling Water System

A closed-cycle cooling water system at MLPP could reduce intake effects by reducing the use of seawater for cooling. This alternative would replace the once-through ocean cooling water system proposed for the new CC units with either a recirculating cooling water system and cooling tower(s) or air cooled condensers.

With the cooling tower scheme, warm water from the steam turbine condensers and other cooling water users in the plant would flow to a new cooling tower(s) consisting of air-water contact surfaces (slats) and electric motor-driven fans, in the case of a mechanical draft tower, or contact surfaces contained in what is essentially a very large chimney in the case of a natural draft tower. The recirculating water to be cooled falls from the top through the tower where it contacts a high air flow drawn through the tower by the fans or the draft of the chimney. Cooling occurs through partial evaporation of the falling water (similar to the operation of a “swamp” cooler) and contact cooling of the water by the cooler air. Cooled water collects in a large basin beneath the tower where cooling water circulation pumps return the water to the condensers and other equipment uses to repeat the cycle.

Recirculating water is lost from the process principally in two ways: evaporation from the tower and a “blowdown” (purge) stream. The blowdown stream is intentionally removed to prevent the buildup of dissolved solids in the recirculating water since the solids do not evaporate in the tower. A third minor loss consists of liquid water droplets (drift) entrained with the air and water vapor leaving the top of the cooling tower. The evaporation, blowdown, and drift losses must be replenished by adding replacement (“makeup”) water to the system. For a seawater recirculating cooling system serving the new CC units, the estimated ocean water required for makeup is about 4.8 percent of the proposed once-through cooling water intake rate and consequently the entrainment of organisms could be reduced up to 95.2 percent.

In an air-cooled condenser system, exhaust steam from the steam turbine generator is cooled and condensed in a large external heat exchanger using atmospheric air as the cooling medium. Large, electric motor-driven fans move large quantities of air across finned tubes (similar in principle to an automobile radiator) through which the exhaust steam is flowing. Heat transfer from the hot steam to the air cools the steam causing it to condense. The heated air is exhausted to the atmosphere. In this case, there would be no seawater required for condenser cooling.

Air-cooled condensers for power plants are very large structures and consume significant amounts of power for operation of the fans. They also significantly reduce steam turbine output due to higher condensing temperatures as compared to once-through or recirculating water condensers.

The most important impacts of cooling towers are air quality, ambient noise, and aesthetics. Due to the height and length of cooling tower structures and their visible vapor, cooling towers have a visual and aesthetic impact on the surrounding area. Noise emissions during operation must be considered, particularly with mechanical draft towers. Extra fossil fuel is required to be burned to compensate for the average loss in generation at power plants where mechanical or natural draft towers are retrofitted. This would have a direct effect on air quality.

7.2.2 Intake Location

Alternative intake locations for the new combined-cycle units at the MLPP include submerged offshore and shoreline intake locations. The proposed shoreline intake location and configuration for the new CC units is the base case against which each alternative is compared.

7.2.2.1 Offshore Intake Location

The efficacy of an offshore intake in reducing entrainment depends, to a large degree, on the vertical stratification of entrainable organisms in the water column at the point of water withdrawal. In such a system, a reduction in entrainment is achieved by locating the submerged intake at a depth where the concentration of entrainable organisms is less than at other depths. Although the available data are limited, entrainable organisms are expected to be distributed in approximately equal concentrations throughout the water column as a result of strong tidal and wind mixing and the shallow depths in the immediate area of the MLPP (Subsection 2.2.2).

Water depths are typically less than 30 ft (9 m) within 2,000 ft (600 m) of the existing intake locations. Many species that have planktonic larvae which are susceptible to entrainment, such as flatfishes, rockfishes, white croaker, smelts, and northern anchovy, spawn in the nearshore waters of Monterey Bay and potentially could be more susceptible to entrainment at an offshore intake than under the present configuration. Because of the large tidal exchange between Moss Landing Harbor-Elkhorn Slough and Monterey Bay, planktonic organisms spawned in the harbor-slough, such as gobies and Pacific herring, would be susceptible to entrainment at an offshore cooling water intake sited in the area adjacent to the Moss Landing Harbor entrance channel. Furthermore, very little if any vertical stratification in the concentrations of planktonic eggs and fish larvae is expected to occur in these shallow areas, which are subject to mixing and turbulence from tidal currents, waves, and wind. Because the waters near the plant are well-mixed from surface to bottom by virtue of the large tidal prism and the turbulence at the entrance to Moss Landing Harbor at both flood and ebb tide stages, an offshore intake structure would not be expected to reduce the numbers of organisms entrained.

For reducing the number of impinged organisms, the effectiveness of a submerged offshore intake depends on locating the intake in an area where such impingeable organisms are not abundant. Many of the dominant groups of fishes and invertebrates (e.g., flounder and sole, rockfishes, white croaker, surfperches, crabs, shrimp) are typically found in association with the offshore bottom habitat in the vicinity of the site, and many of the typically pelagic fish species, such as smelts, northern anchovy, and Pacific herring, are commonly found in large schools which move through the water column, often concentrating near the bottom substrates during the daytime (EA, unpublished). In addition, submerged offshore intakes generally have higher approach velocities than onshore systems and use conduits within which fishes can become entrapped, resulting in an increase in the number of organisms impinged. Furthermore, there is a distinct possibility that the physical presence and nature of an offshore intake would attract many of the fishes and invertebrates inhabiting Monterey Bay (particularly surfperch, rockfishes, and crabs) to the intake location, and so increase the probability of entrapment and subsequent impingement. Thus, use of a submerged offshore intake system would probably result in rates of impingement higher than those observed at the existing intakes.

In summary, an offshore intake appears to offer little or no potential for reducing the losses of fishes and invertebrates entrained or impinged at the new combined-cycle units intake. The susceptibility of planktonic organisms to entrainment would not be reduced by relocating the intake offshore, where tidal currents and turbulence are expected to contribute to a homogeneous vertical distribution of planktonic organisms. The offshore intake would also contribute to the entrapment of fishes and invertebrates, many of which may be behaviorally attracted to the offshore intake. In addition, relocation of the intake offshore would create a navigational hazard at the entrance channel to Moss Landing Harbor, and as such, might not be permitted by the responsible regulatory agencies. In the absence of any evidence of a clear potential for reducing entrainment and impingement losses, an offshore intake location is not considered to be an acceptable alternative for the new CC units.

7.2.2.2 Alternative Onshore Location

The general similarity of the shore-zone habitat along the shoreline of Moss Landing Harbor or Elkhorn Slough suggests that the potential for entrainment and impingement would not be substantially different at any other available shoreline locations. The pattern of tidal currents and mixing in the area resulting from the large volume of the tidal prism relative to the volume of the harbor-slough (Subsection 2.2.0 supports the conclusion that the concentrations of organisms are similar throughout the local shore zone).

During 1971 and 1972, PG&E (1973) conducted a fishery survey at four sampling stations in Moss Landing Harbor and Elkhorn Slough. Sampling was done quarterly with otter trawls and both sinking and floating gill nets. A total of 713 fishes was collected from the harbor-slough system during three sampling periods. Statistical analyses were performed to determine whether differences in catches of fishes among the various sampling stations in the harbor and slough were statistically significant. There were no statistically significant differences in the numbers of fishes collected, the numbers of species, the average weights, or the average lengths of fishes collected at the various sampling stations throughout Moss Landing Harbor and Elkhorn Slough. The results of this series of fishery collections provide no evidence that alternative shoreline intake locations are available in Moss Landing Harbor or Elkhorn Slough that would result in reduced rates of impingement.

Studies by Nybakken, Cailliet, and Broenkow (1977) of fish populations in the Moss Landing area suggest that fish abundance is generally higher near the Highway I Bridge than in the area adjacent to the harbor entrance in Monterey Bay. Fish abundance was intermediate at sampling stations in Elkhorn Slough. However, since no samples were collected in Moss Landing Harbor near the existing cooling water intake locations, the results of these studies cannot be used for comparisons useful in evaluating potential alternative intake locations that might contribute to a reduction in impingement losses.

Data collected on the concentrations of fish eggs and larvae and macroinvertebrates during plankton surveys at six stations located throughout Moss Landing Harbor and Elkhorn Slough (EA, 1982) provide no evidence that alternative shoreline intake locations are available in the harbor-slough system that would reduce entrainment losses. Average daily concentrations of fish eggs were not significantly different among stations sampled in Moss Landing Harbor, although concentrations there were consistently higher than those from the upper slough stations at the Dairies and Kirby Park. Although the concentrations of fish larvae were lowest at the sampling station directly adjacent to the existing cooling water intakes, differences in concentrations were not significant among stations in the harbor and lower slough. Highest larval fish concentrations occurred at stations in the upper slough at the Dairies and Kirby Park. No significant differences in the numbers of larval fish taxa were detected among all stations surveyed in the harbor and slough. There were no significant differences between the average daily concentrations of macroinvertebrates collected at the Dairies in upper Elkhorn Slough, at the station near the Highway I Bridge, at the Moss Landing Harbor entrance channel, or adjacent to the existing cooling water intake locations. Macroinvertebrate concentrations were lowest at Kirby Park in the upper slough and at the station adjacent to the existing intake locations in Moss Landing Harbor. The results of these surveys indicate that planktonic organisms susceptible to entrainment are distributed by tidal currents and by habitat preference throughout Moss Landing Harbor and Elkhorn Slough. No alternative shoreline intake location has been identified that would result in a reduction in entrainment losses.

7.2.3 Behavioral Barriers

Strobe lights have effectively repelled several different fish species in laboratory and field experiments. Recent studies have demonstrated that various lacustrine, riverine, and anadromous species will avoid strobe light. Conversely, some studies have indicated that certain species from similar environments or with similar life history strategies or phylogeny will not respond to strobe lights in a laboratory setting or under field conditions (Brown, 1999).

Air bubble curtains generally have been ineffective in blocking or diverting fishes in a variety of field applications. Air bubble curtains have been evaluated at number of sites on the Great Lakes with a variety of species. All air bubble curtains at these sites have been removed from service.

The focus of recent fish protection studies involving underwater sound technologies has been on the use of new types of low- and high-frequency acoustic systems that have not previously been available for commercial use. High-frequency (120kHz) sound has shown to effectively and repeated repel members of the genus *Alosa* (American shad, alewife, and blueback herring at sites throughout the U. S. (Ploskey et al., 1995; Dunning, 1995; Con Ed., 1994). Other studies have not shown sound to be consistently effective in repelling species such as largemouth bass, smallmouth bass, yellow perch, walleye, rainbow trout (EPRI, 1998), gizzard shad, Atlantic herring, and bay anchovy (Con Ed., 1994). Given the species-specific responses to different frequencies that have been evaluated, and the variable results that often have been produced, additional research is warranted at sites where there is no or limited data to indicate that the species of concern may respond to sound.

In the near field, fish response to "sound" is probably more related to particle motion than acoustic pressure. Particle motion is very pronounced in the near field of a sound source and is major component of what fishes most likely sense from infrasound (frequencies less than 50 Hz). In the first practical application of infrasound for repelling fishes, Knudsen et al. (1992, 1994), found a piston-type particle motion generator operating at 10 Hz to be effective in repelling Atlantic salmon smolts in a tank and in a small diversion channel. Following the success of Knudsen et al. (1992, 1994), there was a general belief in the scientific community that infrasound could represent an effective fish repellent since there was a physiological basis for understanding the response of fishes to particle motion. The potential for currently available infrasound sources to effectively repel fishes has been brought into question by the results of more recent studies. Given these results, it appears that infrasound sources need to be further developed and evaluated before they can be considered an available technology for application at CWIS.

Response to mercury light has been shown to be species specific; some fish species are attracted, others repelled, and others have demonstrated no obvious response. Therefore, careful consideration must be given for any application of mercury lights to avoid increasing impingement of some species.

Electric barriers have been shown to effectively prevent the upstream passage of fishes. However, a number of attempts to divert or deter the downstream movement of fishes have met with limited success (Bengeyfield, 1990; Kynard and O'Leary, 1990). Consequently, past evaluations have not lead to permanent applications. Electric barriers have been used with limited success in freshwater, but because of low electrical resistance, no application of electric fish barriers has been made in salt or brackish waters. Given their past ineffectiveness and hazard potential, electric screens are not considered a viable technology for application at CWIS.

A velocity cap was not considered, since its applicability is restricted to offshore intakes, which were rejected for possible use at the plant (Subsection 7.2.2.1).

In general, behavioral barriers have not proven consistently effective in reducing the numbers of fishes impinged at CWIS. In addition, such barriers are not expected to reduce the numbers of entrained organisms or the impingement rates of macroinvertebrates. Behavioral barriers are not considered to represent an effective alternative for reducing entrainment or impingement at the plant.

7.2.4 Physical Barriers

The applicability of physical barrier screens, such as vertical traveling screens, centerflow screens, barrier nets, and the relatively new Gunderboom for reducing biological losses associated with entrainment and impingement at the new combined-cycle units is evaluated in the following discussion.

Traveling screens of various types (e.g., through-flow, dual-flow, and center-flow with coarse and fine mesh) are standard features at CWIS. Without the addition of various fish handling design (e.g., fish lifting buckets) and operating features (e.g., continuous screen operation), traveling screens generally result in high mortality to all but the hardiest species that become impinged on them. They have no capacity for protecting entrainable sized organisms. If these screens are placed relatively flush with the face of the CWIS, as proposed for the CC units, traveling screens can be considered to offer protection to juvenile and adult fishes that have the swimming capability to avoid impingement.

Under the proper hydraulic conditions (primarily low velocity) and without heavy debris loading, barrier nets have been effective in blocking fish passage into water intakes. Several recent applications in the midwest United States have been presented (Michaud and Taft, 1999). At the Ludington Pumped Storage Plant on Lake Michigan, a 2.5-mile long barrier net, set in open water around the intake jetties, has been successful in reducing entrainment of all fish species that occur in the vicinity of the intake (Reider et al., 1997). The net was first deployed in 1989. Modifications to the design in subsequent years led to a net effectiveness for target species (five salmonid species, yellow perch, rainbow smelt, alewife, and chub) of over 80 percent since 1991, with an effectiveness of 96 percent in 1995 and 1996.

In 1993 and 1994, Orange and Rockland Utilities, Inc. sponsored a study of a 3.0-mm, fine mesh net at its Bowline Point Generating Station on the Hudson River (LMS, 1996). In 1993, fine suspended silt caused the net to clog and sink. In 1994, spraying was not effective in cleaning the net when it became fouled by the algae *Ectocarpus* spp. Excessive fouling caused two of the support piles to snap, ending the evaluation (LMS, 1996). In both years, abundance of the target ichthyoplankton species, bay anchovy, was too low to determine the biological effectiveness of the net. On the basis of studies to date, the researchers conclude that a fine mesh net may be a potentially effective method for preventing entrainment at Bowline Point. However, pending further evaluation, this concept is considered to be experimental.

In conclusion, barrier nets can be considered a viable option for protecting fishes provided that relatively low velocities (generally less than 1 ft/sec) can be achieved and debris loading is light. A thorough evaluation of site-specific environmental and operational conditions is generally recommended. The application of barrier nets at MLPP is not considered practicable given the potential debris loading that exists.

The Gunderboom consists of polyester fiber strands which are pressed into a water-permeable fabric mat. Beginning in 1995, Orange & Rockland Utilities, Inc. has sponsored an evaluation of the Gunderboom to determine its ability to minimize ichthyoplankton entrainment at the Lovett Generating Station on the Hudson River (LMS 1996b, 1997, and 1998; ASA, 1999). Despite difficulties in keeping the boom deployed and providing adequate cleaning in 1995-1997 studies, results of studies in 1998 show a large reduction in entrainment and it appears that deployment and cleaning problems may have been resolved for this site. At this time, the Gunderboom system is still considered to be experimental but its successful use at Lovett may change that status within several years.

7.2.5 Fish Collection, Removal, and Conveyance Systems

Several modifications to conventional vertical traveling screens have been considered in recent years in an attempt to increase their biological effectiveness. Some information is available on the effectiveness of various screen rotation frequencies from studies conducted at the MLPP (see PG&E, 1983; Section 4.2). Information is also available for impingement survival of chinook salmon from the Columbia River (Page et al., 1976, 1978) and of striped bass from the Hudson River (EA, 1979; Texas Instruments, Inc., 1977). Data from these and other studies are used in a general way to provide additional information useful in examining the potential effectiveness of modified vertical screens at the new combined-cycle units. The effectiveness of screen modifications for reducing impingement losses is discussed in Subsections 7.2.5.1 through 7.2.5.4.

In addition, consideration has recently been given to the potential effectiveness of a screen mesh smaller than the standard 3/8 in. (9.5 mm) but larger than 0.04-in. (1.0-mm) fine-mesh screen material for reducing the combined losses of entrainment and impingement.

Modifications to the design and operation of vertical traveling screens, such as the use of continuous screen rotation, low-pressure spray washes, and fish lifting buckets, are alternatives that have been used to increase the biological effectiveness of conventional vertical traveling screens. In many cases, continuous screen rotation has resulted in substantial increases in fish and invertebrate survival. Increasing screen rotation frequency at the MLPP Units 6 and 7 intake contributed to a substantial increase in impingement survival for both surfperch and rockfishes (see PG&E, 1983; Table 4-7). However together these species constituted only 15 percent of the fishes impinged at the Moss Landing Power Plant. The use of these modifications would have no benefit without a fish return system. However, these studies also suggest that impingement survival of species such as northern anchovy, Pacific herring, smelt, and silversides, which together constituted approximately 75 percent of the impinged fishes, will probably not be improved substantially by increased screen rotation frequency.

Limited information is available to assess the potential of this modification for improving impingement survival for the species of fish impinged in greatest abundance at the Moss Landing Power Plant (Section 5). Among these, species such as plainfin midshipman, gobies, and crabs appeared to have high survival, but fragile species such as northern anchovy, Pacific herring, smelt, and silversides had low survival on the existing intake screens. Although available data are incomplete, it is expected that survival of fragile species would be increased by the addition of fish buckets, low-pressure spraywashes, and continuous rotation of screening surfaces. In particular, impingement survival of surfperch and rockfishes is expected to increase.

7.2.5.1 Fine-Mesh Screens

In addition to the fish handling provisions noted above, traveling screens have been further modified to incorporate screen mesh with openings as small as 0.5 mm to collect fish eggs and larvae and return them to the source water body. For many species and early life stages, mesh sizes of 0.5 to 1.0 mm are required for effective screening. Various types of traveling screens, such as through-flow, dual-flow, and center-flow screens, can be fitted with fine mesh screen material.

The absence of data on the impingement survival of the fish eggs and larvae present in the vicinity of the MLPP and the uncertainties regarding operational reliability of fine-mesh screens in a marine environment similar to that of Moss Landing Harbor-Elkhorn Slough preclude the conclusion that fine-mesh would be a biologically effective and operationally acceptable alternative intake technology for use at the new CC units.

7.2.5.2 Fish Return Conveyance Systems

There are two basic types of conveyance for the return of impinged organisms and debris to the waterbody, one using a trash pump to transport material away from the intake and one using gravity flow. The pump-augmented return has the advantage of minimizing recirculation and re-impingement of debris and organisms on intake screens due to relatively large transport distance capability, but often results in mechanical abrasion and high mortality of organisms. The gravity sluiceway return system reduces mechanical abrasion, but may cause significant reimpingement because of relatively limited transport distances. It is concluded that no further consideration should be given to a fish pump return system for diverting fishes from new CC units intake because of the uncertainties associated with the effectiveness of such a system in successfully diverting the fish species found at the site and returning them alive to Moss Landing Harbor. Fishes that were returned alive to the Harbor would be susceptible to disease and predation at the fish return discharge point due the stress of passage through the pumped fish return system.

Previous studies have concluded that the potential magnitude of reduction in impingement losses attributable to a gravity fish conveyance system is uncertain (PGandE,1983). However, the combination of a modification to the screens and their operation and the installation of a modified screenwash gravity sluiceway return system for the proposed CC units may have potential for improving impingement survival and will be considered in the in the next step of the analysis. Because of the uncertainties associated with determining the biological effectiveness and various engineering design and operational considerations, a testing program would be required prior to implementing a modified screen system at the new CC units intake.

7.2.5.3 Summary

Modifications of vertical traveling screens that include fish buckets, a low-pressure wash system, provisions for continuous rotation, and a fish return system represent an alternative technology with the potential for reducing impingement losses of several of the species of fish and invertebrates impinged at the proposed new CC units intake structure. In the absence of a demonstrated potential for long-term survival for impinged ichthyoplankton, such as northern anchovy, Pacific herring, surfperch, rockfishes, white croaker and flatfishes, fine-mesh screens are not considered to represent an acceptable alternative intake technology for use in reducing the combined losses resulting from entrainment and impingement at the modified intake. Insufficient data preclude a detailed comparison of the potential survival of fish eggs and larval fishes impinged on modified vertical traveling screens (fine-mesh screen material, fish buckets, low-pressure spraywash, continuous rotation) and centerflow screens (fine-mesh screen material, continuous rotation). To date, no studies have been conducted of long-term survival of fishes impinged on centerflow screens operated in a power plant cooling water intake, and it is unlikely that survival would be any higher than for vertical traveling screens. Preliminary test of the Gunderboom barrier net (Section 7.2.4) indicate that this technology is both reliable and effective at eliminating impingement and dramatically reducing entrainment effects. Installation and operation of a barrier screen is feasible for the MLPP CC units.

7.2.6 Intake Maintenance And Operational Modifications

Maintenance activities and operational modifications which may reduce entrainment and impingement losses include maintenance dredging in front of the cooling water intake, reductions in circulating water pump volume, seasonal curtailment of cooling system operation, use of alternative biofouling schemes, structural modifications of the cooling system, and through-plant temperature regulation.

7.2.6.1 Maintenance Dredging

Sediment accumulation within a cooling water intake structure may reduce the open area of the intake, resulting in increased water velocities. Increased velocities approaching the intake structure will, in many cases, result in increased rates of impingement. Depth measurements made in the intake structure of the Moss Landing Power Plant (PG&E, unpublished) indicated that sediment had accumulated that would reduce the available cross-sectional area of the intake (Subsection 2.1.3.2). Sediment accumulation in retired Units 1 through 5 intake structure had reduced the cross-sections of the forebays by an average of 30 percent, ranging from 10 percent of Bay 3 to 52 percent of Bay 1. Bays 1 and 6 had the lowest mean intake velocity, and the velocity at Bay I was lower than expected from the degree of blockage. These anomalies were attributed to the previous hydraulic characteristics of the Units 1 through 5 intake structure and the considerable distance to the circulating water pumps. Sediment accumulation in the Units 6 and 7 intake was considerably less than that in the Units 1 through 5 intake. Accumulated sediment had reduced the cross-sections of the Units 6 and 7 forebays by an average of 13 percent, ranging from 10 percent at Bay 7-3 to 18 percent at Bay 6-1. The reduction in the number of organisms impinged that would result from removing accumulated sediment and reducing intake velocities cannot be estimated on the basis of available data. There is little doubt, however, that maintenance dredging of the plant intakes would reduce approach velocities and potentially reduce the number of impinged organisms. A disadvantage of dredging is that the re-suspension of sediments has a potential negative impact on nearby benthic invertebrates, particularly filter feeders. Consequently, while dredging the intake might reduce impingement losses, a reduction in population concentrations of some benthic invertebrates would be expected during and shortly after the dredging.

7.2.6.2 Circulating Water Pump Volume Reduction

A reduction in the number of circulating water pumps in operation and/or installation of variable-speed circulating water pumps represents an alternative operational strategies for reducing cooling water volumes and intake approach velocities, and hence reducing the number of organisms entrained and possibly those impinged. Changes in condenser back-pressure resulting in reduced turbine cycle thermal efficiency, along with increased temperature differentials through the condenser system (delta-T), are to be expected when cooling water flow rates are reduced during generation. Although a reduction in cooling water volume is expected to result in a decrease in the number of entrained organisms, the associated increase in delta-T would increase the discharge temperature and thermal plume size.

Reducing the operation of the circulating water pumps during periods when generation is low or is not occurring would reduce the numbers of organisms entrained and possibly those impinged. Because of the entrainment mortality resulting from predation by biofouling organisms that colonize the cooling water system conduits at the plant, entrainment losses are expected to be reduced in approximately the same proportion as the reduction in cooling water flow rates. Examination of monthly capacity factors (see PG&E, 1983; Tables 2-2 and 2-5) and monthly cooling water volumes (see PG&E, 1983, Tables 2-3 and 2-6) indicates that circulating water pump operation typically exceeds generation. Although the reduction in entrainment losses that could be achieved through a reduction in circulating water pump operation has not been precisely quantified, it is concluded that this alternative operational mode offers the potential for reducing entrainment losses.

The number of fishes impinged is expected to be reduced by reducing circulating water pump operation. However, no data are available from the 1979-1980 impingement study (Section 5) to quantify the magnitude of reduction in fish impingement that would result from various circulating water pump operational modes. Additional studies would be required to quantify the effect on impingement of short-term reductions in pump operation.

Despite the lack of quantitative data, it is concluded that short-term (hourly or daily) reductions in the volume of cooling water that coincide with reduced generation have a high probability of reducing entrainment and impingement losses.

7.2.6.3 Seasonal Curtailment of Energy Production

Seasonal curtailment of cooling system operation could reduce the numbers of organisms lost by entrainment and impingement. The amount of the reduction depends on the length of time the cooling system is out of operation and the concentration of organisms during the period of curtailment. Based on the seasonal distribution of entrainment and impingement (PG&E, 1983), two peak periods of abundance, February through March (the peak period of northern anchovy, goby, and silverside entrainment in 1978-1980) and August through September (the peak period of impingement in 1978-1980), were selected as possible periods for curtailment. Seasonal curtailment of cooling system operation would result in a reduction in the numbers of organisms entrained and impinged, and is therefore considered to be an alternative technology for further consideration for the new CC units.

7.2.6.4 Alternative Biofouling Schemes

The biofouling control procedure currently used at the Moss Landing Power Plant consists of intermittent chlorination (Subsection 2.1.2) for slime control and heat treatment for biofouling control. These control schemes have been adequate to control marine growth and are planned for application to the new CC units as well.

Alternative biofouling control schemes which can be considered for application at the new combined cycle units include the following:

1. relocation of the proposed chlorine injection point for new cc units to the modified Units 1 through 5 intake head works,
2. increased chlorine dosage,
3. increased frequency of chlorination from intermittent dosage to continuous application,
4. use of alternative chemical toxins, including bromine, chlorine dioxide, chlorine bromide, and ozone,
5. application of toxic coatings on cooling system conduit walls,

6. oxygen depletion (stagnation),
7. mechanical cleaning,
8. increased heat treatment, and
9. increased water velocities within cooling system conduits.

All of these alternatives, with the exception of increasing chlorination frequency to continuous application and increased water velocities within the cooling water conduits, are expected to have the potential of reducing entrainment cropping by controlling the colonization of cooling water system conduits by marine fouling organisms. Because of the toxicity of chlorine to non target organisms (entrained fish eggs, larvae, and juveniles and invertebrates), continuous chlorination would potentially result in 100 percent entrainment mortality. Increasing the velocity of cooling water through the conduits to levels above 10 fps (300 cm/sec) has the potential of reducing colonization by marine organisms. Increasing cooling water velocities would, however, substantially increase mechanical damage to entrained ichthyoplankton and macroinvertebrates and increase impingement losses. Increasing velocities within the cooling water conduits is therefore not considered to be an effective method of reducing the combined losses resulting from entrainment and impingement at the new combined cycle units.

As described earlier, the proposed project includes modifications to the existing Units 1 through 5 intake system to allow periodic heat treatment for removal of biofouling organisms after the new CC units are installed. This new heat treatment capability should reduce the level of predation on entrained organisms experienced with the historic Units 1 through 5 operation and no further changes to the proposed system should be necessary.

Further discussion is given in Subsection 7.3.6 regarding the current anti-fouling program for Units 6 and 7 as well as the proposed program for the new CC units.

7.2.6.5 Discharge Temperature Regulation

Discharge temperatures are relatively low at the MLPP throughout the year. In 1999, the annual average discharge temperature was 69° F, with a peak 24-hr discharge temperature of 81°F.[1] Exposure to discharge temperatures above 86° F (30° C) during cooling system transit are lethal to entrained striped bass larvae. Therefore, thermal stresses are not expected to be a significant cause of mortality to entrained fishes or invertebrates. Discharge temperature regulation is not expected to result in a significant reduction in entrainment losses since nearly 100 percent of the organisms are lost to biofouling predation in the cooling system (PG&E, 1983).

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[1] 1998 NPDES Discharger Self-Monitoring Report for MLPP

7.2.6.6 Cooling System Modifications

Structural modification of cooling system components (pumps, conduits, condensers) is not considered to be an effective alternative to reduce the mortality of entrained organisms. Too little quantitative information is available to isolate specific sources of mortality within a cooling water system. Design parameters for specifying pressure regimes, circulating water pump design and operation, tolerable shear stresses, and cooling system designs for minimizing mechanical abrasion have not been developed.

7.2.7 Conclusion: Biological Evaluation

Based on results of the biological evaluation (Section 7.2), the following was concluded:

1. There are no reasonable alternative intake locations that would reduce entrainment and impingement losses,

2. Behavioral barriers would not be expected to reduce numbers of organisms exposed to either entrainment or impingement,

3. Entrainment and impingement losses would not be substantially reduced by use of traveling screens, barrier nets, a Gunderboom, or a fish pump system,

4. A screen mesh size of 5/16 in. (0.8 cm) is acceptable; there is insufficient data available to determine whether the survival of fish eggs and larvae impinged on fine-mesh screens would exceed the survival of organisms entrained through the MLPP cooling systems, and

5. Cooling system structural modifications and discharge temperature regulation are not expected to reduce the mortality of entrained organisms substantially.

The following alternative intake technologies may reduce entrainment and/or impingement losses for the new CC units and were therefore selected for feasibility analysis:

1. seasonal curtailment of cooling system operation,

2. replacement of the proposed once-through cooling system with a closed-cycle system (either salt water cooling tower(s) or air cooled condensers),

3. modified vertical traveling intake screens and gravity screenwash fish return system for the revamped Units 1 through 5 shoreline intake structure to be used for the new combined-cycle units,

4. short-term reductions in circulating water pump operation when the units are operating at low loads or are out of service,
5. periodic dredging of the intake area to reduce intake velocities, and
6. alternative biofouling control schemes.

7.3 Third-Level Evaluation — Feasibility And Cost Analysis

Each alternative technology that satisfied the biological reduction criterion (Section 7.2) and differed in design or operation from that presently proposed for the new CC units cooling water system was evaluated with regard to engineering feasibility, operation, and reliability. In addition, the total economic cost in 1999 dollars associated with each feasible alternative was estimated. Cost estimates reflect direct capital costs and indirect costs (e.g., the loss of generating capacity) where applicable.

7.3.1 Seasonal Curtailment

Section 7.2.6.3 identifies seasonal curtailment of cooling system operations to reduce entrainment and impingement losses. The economic consequences of seasonal curtailment are such that Duke Energy would not construct a CC plant that could not operate for four months of the year. In this scenario, existing Units 6 and 7 would continue to operate at high capacity levels in the absence of new, more efficient generation at MLPP. Continued use of Units 6 and 7 in the absence of new generation would result in greater impingement/entrainment since the impacts of Units 6 and 7 are greater than the proposed CC plant.

Once the CC plant is constructed, seasonal curtailment of the new CC units will likely be infeasible because of increasing demand for electrical energy in the central and northern California load centers and the uncertain availability of surplus energy from other sources to replace it. Setting aside the question of alternative energy sources to reliably serve customers and the demand for electricity, the estimated costs of replacement energy alone that would result from curtailment of operation of the new CC units from February through March (the peak period of northern anchovy, goby, and silverside entrainment from the 1979 -1980 MLPP 316(b) study) and from August through September (the peak period of impingement determined from the same study) are summarized in Table 7-2, based on expected operation of the new CC units and recent system power price projections. The estimated net loss of future power sales revenue corresponding to the curtailment of new CC units operation during February through March plus August through September is about $59 million per year. Fluctuating fuel costs, which are a major factor in the cost of replacement energy, make accurate projections of net future energy revenue difficult. If curtailment could be implemented during these two periods, it could reduce biological losses resulting from both entrainment and impingement. This curtailment strategy, however, is particularly inappropriate since it would severely reduce electrical generating capacity during the critical summer period when electrical demand is highest.

An alternative approach to using curtailment to reduce biological losses is to schedule maintenance outages to coincide with periods of greatest biological loss. However, it is inappropriate to schedule maintenance during the critical summer period. It may be possible to schedule maintenance during February and March when electrical loads are not as high and when other resources such as hydropower are more readily available. However, scheduled maintenance outages for fossil-fueled plants are generally of much shorter duration than at nuclear-fueled plants, where this option has sometimes been considered.

It is not expected that frequent significant scheduled outages for the new CC units will occur. Minor maintenance outages for cleaning of the new units will be scheduled for short periods, about four hours of downtime, approximately once per combustion turbine generator (CTG) unit per month. Annual inspections will also be scheduled for each unit that will require about one day off line per CTG. More thorough inspections, requiring about two days, will take place every three to five years. Major overhauls, requiring an outage of about two weeks, typically occur about every eight years. Therefore, no significant biological benefits could be achieved by attempting to schedule maintenance outages during predicted sensitive periods.

Daily curtailment of cooling system operation (e.g., at night or when load is low) is another alternative approach for reducing biological loss. It is likely that that the new CC units will be turned down or some CTG units taken off line during periods of decreased demand, such as late evening and early morning. However, these units will be among the most efficient fossil fuel units available in the state system and are expected to be used frequently to meet base load demand day and night. Therefore, although it is expected that the new units will sometimes operate at reduced load with corresponding benefits to marine organisms, a commitment to regular curtailment of cooling system operation is considered to be impractical for the new CC units, based on the projected need for highly efficient sources of base load generation and the additional need for rapid response to electrical demands within the system.

The various strategies for curtailment of cooling system operation would result in a reduction of both entrainment and impingement losses in an amount that would depend on the abundance of organisms present during the period of curtailment and the duration of the outage. However, curtailment of operation of the CC units beyond what would occur from normal scheduling is not acceptable, because it removes the generating capacity of the plant from reliable service when it is needed to serve system loads. The availability of replacement power is uncertain. However, if

Units 6 and 7 would continue to operate in lieu of the new generating facilities the impacts on impingement/entrainment would be greater for a given level of power generation.

For the cost, operational reliability, and flexibility reasons discussed above relative to the potential improvements in biological impacts, curtailment of power generation as a method of reducing entrainment and impingement losses for the new CC units is not considered to be a feasible alternative.

Table 7-2. Estimated Cost of Replacement Energy during two Periods of Operation Curtailment for the Moss Landing Combined-cycle Units.

Period of Curtailment	Energy Payment ($MW-hr)*	Fuel Cost ($\$/10^6$ Btu)**	Operating Time (hrs/month)***	Output When Operating (MW)****	Lost Revenue ($)*****
February	27.45	2.52	605	1060	6,614,000
March	34.60	2.48	670	1060	4,713,000
August	55.35	2.46	670	1060	27,429,000
September	45.75	2.48	650	1060	19,902,000
Total					58,658,000

*Projected energy prices for NYMEX California-Oregon border for year 2000, from *Megawatt Daily*, Dec. 22, 1999.

**Projected fuel costs at NYMEX Henry Hub from Gas Daily, Dec. 22, 1999.

***Estimated operating time assuming about 90 percent capacity factor.

****Lost energy payments less avoided costs of fuel (based on nominal heat rate for new CC units of 6,800 Btu/kW-hr.

*****Revenue contributions must cover all operating costs and a return on capital.

7.3.2 Closed-Cycle Cooling Systems

Potentially applicable systems at the MLPP include mechanical or natural draft recirculating cooling towers and air cooled condensers. The operation of these systems is described in Section 7.2. The following sections evaluate the cost and feasibility at MLPP. (The use of these systems would be preferred, from the standpoint of power plant operating economics, to the seasonal curtailment alternative discussed in the previous section).

7.3.2.1 Mechanical Draft Cooling Tower

Two possibilities for a source of recirculating cooling water exist at the Moss Landing site, fresh ground water or seawater. Although freshwater systems have the advantage of smaller makeup water requirements due to less dissolved solids, a continuous freshwater makeup supply of about 5,400 gpm would be required for a freshwater cooling tower system serving the new CC units at MLPP. Due to the current and expected future limitations of freshwater supply in the area, it was decided that a freshwater system was not realistic and the evaluation would consider seawater cooling towers.

Seawater mechanical draft cooling towers for the MLPP CC units would consist of two structures, one for each unit, each approximately 410 ft x 53 ft x 55 ft high. Ocean water makeup for this system would be supplied from the existing Units 6 and 7 cooling water pumps or new pumps at the existing Units 1 through 5 pumpwell. The circulating water and blowdown stream would contain salinity (dissolved solids) approximately 50 percent greater than local seawater. The estimated combined full capacity flow rates for both towers are:

Recirculating water	250,000 gpm
Blowdown (returned to ocean)	7,800 gpm
Makeup (withdrawn from ocean)	12,000 gpm

The blowdown stream will contain residual concentrations of biocides, dispersants, and other conditioning chemicals, in higher concentrations than the existing once-through cooling water discharge. Blowdown will be disposed by discharge to the ocean at approximately 84 °F.

The estimated total installed capital costs associated with the two forced draft mechanical cooling towers for the new CC units including towers, basins, chemical additive systems, and supporting systems are about $12 million more than the proposed once-through cooling water system.[2] Figure 7-1 shows a possible location where the new cooling towers could be installed at MLPP.

Mechanical draft cooling towers would significantly diminish the net power output and operating efficiency of the modernized plant. The combination of the higher steam turbine condenser temperatures caused by the recirculating cooling system and the higher plant electrical load compared to the once-through cooling water case would decrease the net power output available from the new CC units by about 25 MW (for the same fuel consumption). This reduction in capacity will have to be made up by other, probably less efficient and more polluting power sources. The estimated annual revenue losses from this decrease in capacity is approximately $2 million per year.[3] Over the life of the project the use of cooling towers will cost approximately $60 million.

Visible fog plumes could be expected (probably frequent during the winter) due to condensation in the atmosphere of the considerable amount of water vapor emitted from the top of towers.

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[2] Amount shown is the additional capital investment required to substitute cooling towers for the proposed once-through cooling water system.

[3] Based on a net margin approximately $10/MW-hr and a 90 percent capacity factor.

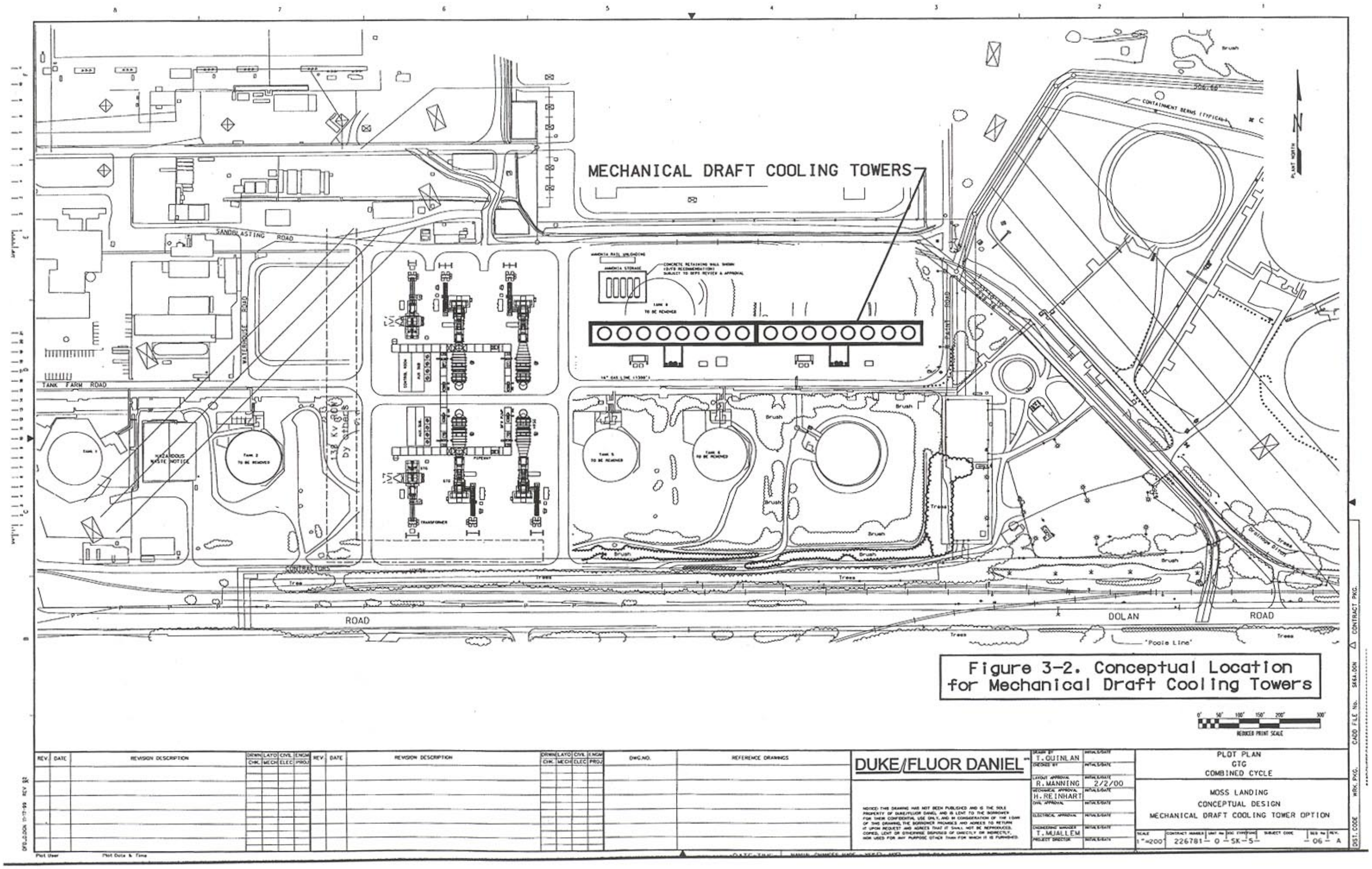

Figure 7-1. Moss Landing Power Plant alternative closed-cycle cooling mechanical draft cooling tower location.

Cooling tower drift "raining" out of the plume could cause a nuisance salt water deposition on the surrounding area which could result in increased equipment maintenance requirements in the plant and adverse effects on nearby agriculture, and at times on local businesses and residences. Drift would also lead to increased fine particulate salt emissions from the facility in the form of dissolved solids emitted with the drift droplets. For the salt water tower considered, the estimated additional particulate emissions to the atmosphere associated with drift would be about 750 lb/day.[4] This quantity would represent a substantial increase in PM10 emissions from the project and could cause adverse air quality impacts.

Mechanical cooling towers are a significant potential source of overall power plant noise impacts on surrounding areas due to the significant quantity of elevated equipment such as fans, motors, and gears.

For all the above reasons, the proposed once-through cooling water system is preferred to a mechanical draft tower.

7.3.2.2 Natural Draft Cooling Tower

A natural draft cooling tower system is very similar in principal to the mechanical draft system. The primary difference is that the mechanical fans to move the cooling air are replaced by what is essentially a very large chimney. Air is drawn in at the base of the tower due to the less dense (more buoyant), warmer air exiting the top of the tower. This natural air circulation contacts the returned cooling water inside the tower and cools the water by evaporation and direct contact with the cooler air. Thus the cooling water recirculation, blowdown, and makeup rates and quality are about the same as for the mechanical (forced draft) system.

A natural draft cooling tower to serve the Moss Landing combined-cycle units would be approximately 250 feet in diameter at the base and about 370 feet in height. Figure 7-2 shows a conceptual location for the new natural draft cooling tower.

The estimated total installed cost for natural draft tower is about $13 million more than the proposed once through cooling water system[5]

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[4] Assuming drift is 0.0005% of recirculating water.

[5] Incremental capital investment for natural draft cooling tower in lieu of proposed once-through cooling water system.

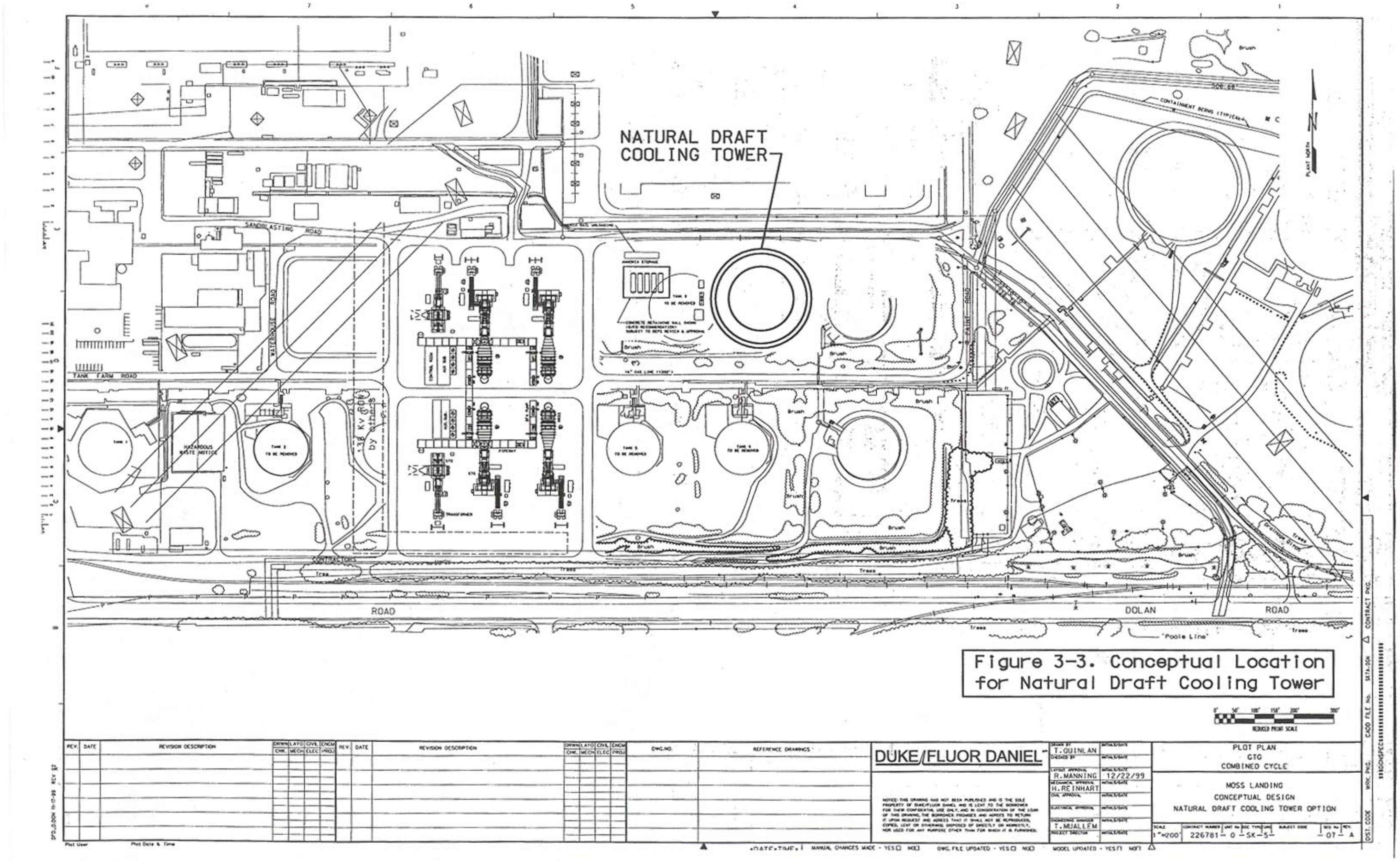

Figure 7-2. Moss Landing Power Plant alternative closed-cycle cooling natural draft cooling tower location.

Most of the potential negative impacts described for the mechanical draft towers would also be associated with a new natural draft tower for the MLPP. The blowdown discharge to the ocean would be the same. Drift losses and the resulting PM10 emissions would also occur, although at somewhat reduced rates. Noise impacts would be less. The auxiliary power requirement would be reduced, due to the lack of mechanical fans, but the steam turbines output would still be decreased by about 22 MW. The estimated annual revenue losses from this decrease in capacity are approximately $1.7 million per year.[6] Over the 30-year life of the project the use of a natural draft cooling tower will increase power costs by approximately $51 million.

Visible condensate plumes would also periodically occur at the top of the tower and, obviously, the overall visual impact due to the size of the tower is much more significant.

This alternative was eliminated, primarily because of the very adverse visual impacts of such a massive structure and the high capital investment required.

7.3.2.3 Air-cooled Condensers

Air-cooled condensers for power plants are very large structures and consume significant amounts of power for operation of the fans. Noise impacts are substantial and, without extensive abatement, are generally greater than for mechanical towers. Air cooled condensers also significantly reduce steam turbine output due to higher condensing temperatures as compared to once-through or recirculating water condensers.

It is estimated that an air-cooled condensers for the new CC units, one for each unit, would each occupy about 0.75 acre of plot space, extend to a height of 80 to 90 feet. Overall, the net output for the two new CC units would be reduced by a total of more than 60 MW [7] (the size of a small power plant). Figure 7-3 shows the plot space that would be consumed.

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[6] Based on a net margin of $10/MW-hr and a 90 percent capacity factor.

[7] For summertime operation; the corresponding reduction for wintertime operation is about 37 MW.

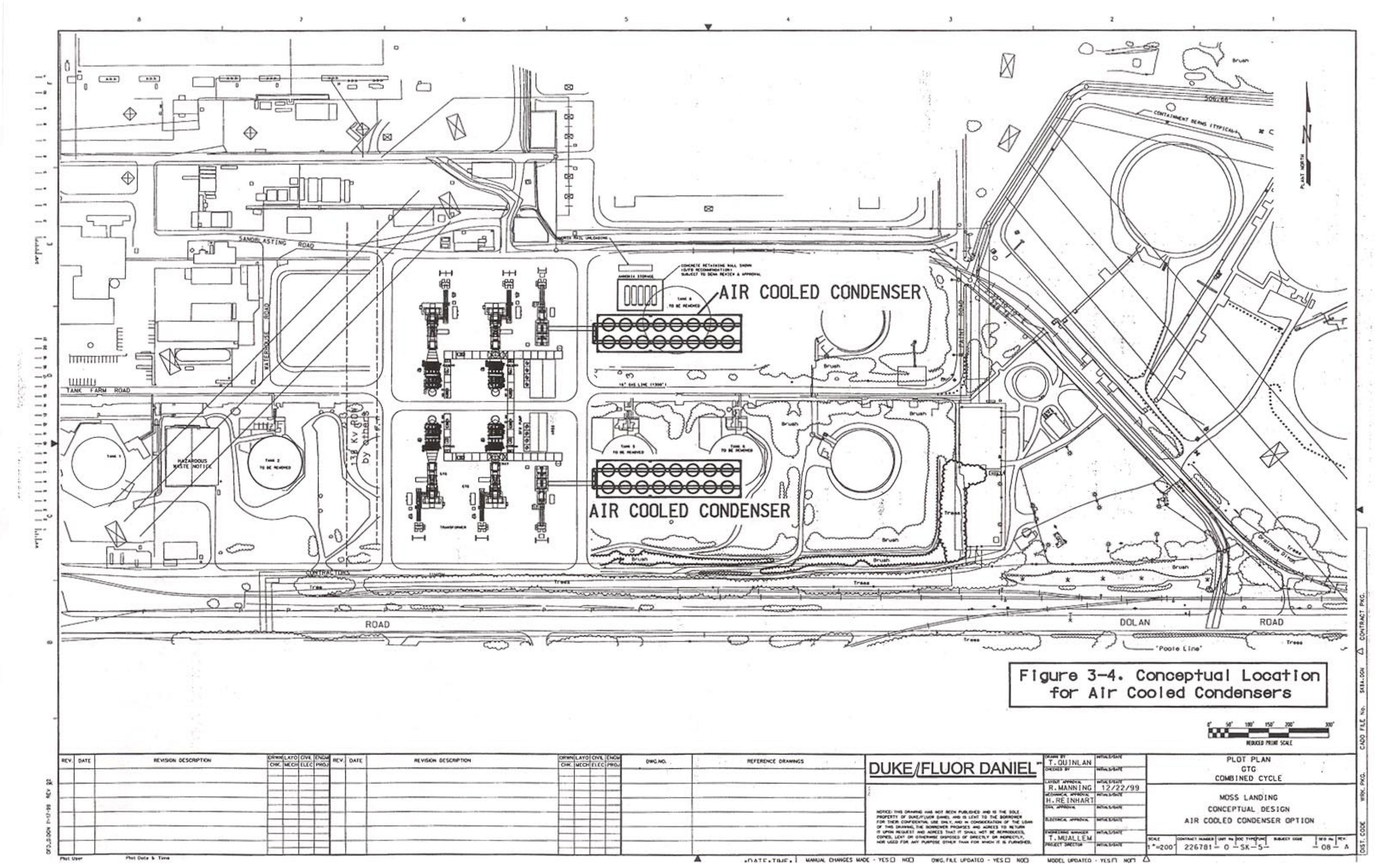

Figure 7-3. Moss Landing Power Plant alternative closed-cycle cooling air-cooled condensers location..

The estimated additional total installed cost for the two air cooled condensers, as compared to the proposed once through cooling system is about $30 million combined total costs for both the CC units. The estimated annual revenue losses from the associated decrease in capacity is about $3.8 million per year.[8] Over the 30-year expected life of the project the use of air cooled condensers would cost about $114 million.

Because of the substantial loss in net power output, the significant adverse visual impacts of these systems, and the very large associated costs, the air-cooled condenser option is eliminated from additional consideration.

7.3.3 Modified Vertical Traveling Screen and Fish Return System for the New CC Units Intake

As described in Section 2, the existing (retired) Units 1 through 5 intake structure will be modified to serve as a shoreline intake structure (inclined screens in the shoreline structure) for the new CC units. This shoreline intake structure will eliminate the large length of intake conduit upstream of the screens and the lower cooling water withdrawal rates will result in decreased intake velocities, both of which should substantially reduce entrapment of organisms within the intake conduit, as compared to the previously used intake configuration. The intake structure and screen configuration will be designed for a screen approach velocity of 0.5 fps (15 cm/sec) at mean lower low water, which is consistent with U.S. EPA guidelines for the design of new cooling water intake structures. At higher tide levels, which will be most of the time, the screen approach velocity will be less.

This alternative evaluates the use of a vertical traveling screen with fish handling features instead of the proposed inclined screen. For some species of fishes, impingement mortality can be reduced through structural modifications to conventional vertical traveling screens and a change in intake screen operation from intermittent to continuous rotation (Subsection 7.2). The structural differences to the currently proposed modifications for the new CC units for this alternative would include replacement of the proposed inclined screen with a conventional vertical screen, installation of watertight fish collection baskets along the screen, both low-pressure and high-pressure wash systems, and a fish return sluiceway. A differential control and two-speed motor are also included, so that when the screen is operated continuously it rotates at slow speed, and as the of number fishes and/or debris loads increase, the screen rotation rate can be automatically increased. In general, 3/8-in. (0.9-cm) screen mesh would be used on modified vertical traveling screens.

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[8] Based on a net margin of $10/MW-hr and a 90 percent capacity factor and assuming an annual average capacity reduction of 48.5 MW.

Screens modified to reduce impingement mortality need to be accompanied by a sluiceway (Subsection 7.2) designed to return impinged organisms to the receiving waterbody. Most installations of modified traveling screens use a dual sluiceway return system, a gravity sluiceway return system for impinged organisms removed from the screens by the low-pressure spraywash and another sluiceway for debris removed by the high-pressure spraywash.

The alternative modified screen system evaluated for the CC units intake structure is shown in Figures 7-4 and 7-5**.** This system would consist of new vertical screens installed in the existing Units 1 through 5 intake structure behind the existing bar racks. The screens would be smooth top mesh and furnished with fiberglass fish baskets and differential speed controls. Low and high-pressure spray wash systems are provided to wash recovered fish and other organisms into a fish trough on the top of the intake structure. Impinged debris will be washed into a separate

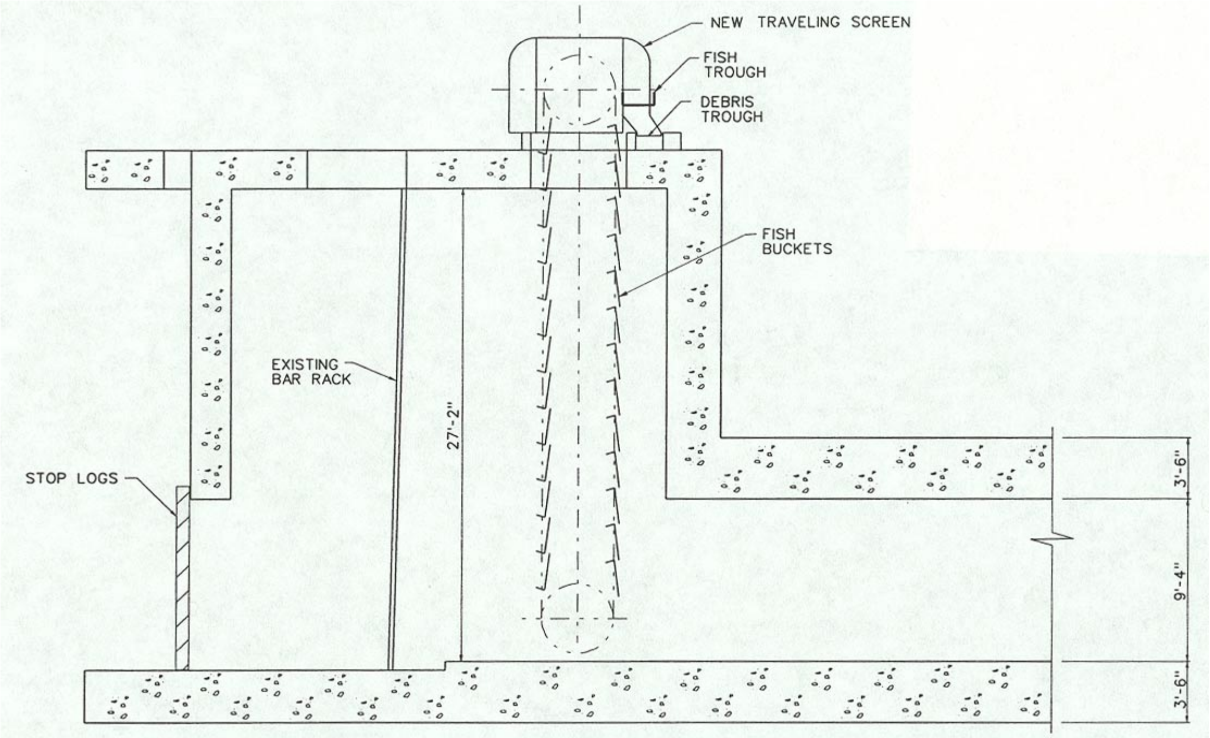

Figure 7-4. Traveling water screen proposal number 1.

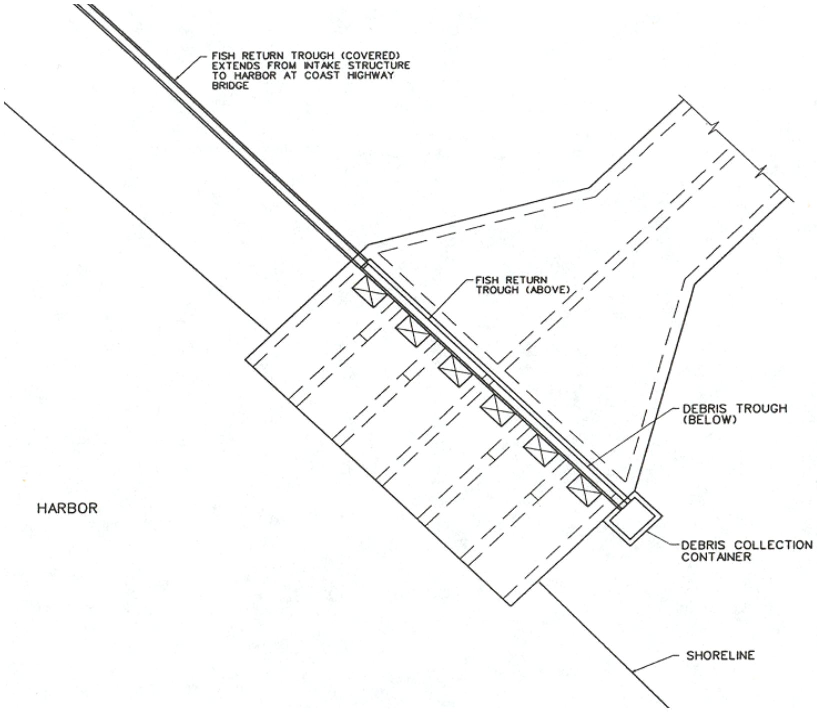

Figure 7-5. Traveling water screen proposal number 1 (overhead view).

debris trough, also on top of the structure. A new water filled fish sluiceway would extend from the fish trough to Moss Landing Harbor to return recovered organisms to the Harbor at the shoreline approximately 800 feet north of the intake structure.

For the new CC units, the incremental capital costs of a modified screen are those associated with the difference in cost for a vertical screen plus the fish handling modifications and fish conveyance system as compared to the proposed inclined screen system. Modification of the proposed inclined screens to vertical intake screens with the additional features described for fish handling (fish baskets, deflectors, dual spraywash system, differential controls, fish return system, etc.) would have an incremental capital cost of approximately $2.6 million more than the proposed inclined screen system.

7.3.4 Reductions in Circulating Water Pump Operation

A reduction in the number of circulating water pumps in operation is an operational strategy for reducing cooling water volume use and intake approach velocities, and hence the rates of entrainment and impingement.

The currently proposed configuration of the new combined-cycle units will allow reduced cooling water pump operation during certain reduced load operating scenarios. As described in Section 2, the presently proposed new facilities consist of two essentially independent 530 MW units. Each unit is provided with two CTG/HRSG trains, which supply steam to one steam turbine generator (STG)/condenser set. Only the STG condensers require the use of significant amounts of cooling water. The STGs are provided for the sole purpose of recovering (in essence recycling) excess heat from the combustion turbines to create additional energy, and thereby are a significant reason for the very high thermal efficiency of the combined cycle process.

Three cooling water pumps per 530 MW unit will supply cooling water to the condenser in the unit they serve (a total of six new cooling water pumps for the entire 1,060 MW addition). If only one of the two new units is operating, only three of the six new cooling water pumps would run to serve it. In certain other operating conditions it may be possible to also reduce cooling water flow rates. For example, if one unit is operating at significantly reduced capacity such as only one of the two CTG/HRSG trains on line, it may possible to satisfactorily operate that unit with only two of its three cooling water pumps operating.

Another approach to reduce cooling water flows to the minimum level necessary to maintain efficient operation of the unit at a specific generating load would be to install variable-flow pumps or modify the existing pumps to incorporate variable features. Since the combined-cycle units are expected to run near full capacity for most of the year, which dramatically reduces the potential benefits of variable flow devices, this alternative will not be evaluated for the new units. As discussed above, it will be possible to reduce the number of CC unit cooling water pumps in operation from six to as few as two during part load conditions which, in effect is a variable flow capability. Units 6 and 7 are expected to operate at reduced loads more frequently in the future especially during lower demand periods. Therefore, the use of variable flow was analyzed for the existing units.

The pumps currently in use for Units 6 and 7 are limited to no-flow or full-flow operation. Since each pump serves only one-half of its unit's split condenser and the steam from the steam turbine flows to both halves of the condenser, both pumps must run when the unit is operating, even at reduced loads. However, with variable-frequency controls or variable flow vanes the Unit 6 and 7 pumps could be operated at cooling water flow rates that match reduced unit loads, reducing the numbers of organisms entrained and impinged. The magnitude of the reductions in entrainment and impingement losses would depend on the reduction in cooling water flows and the abundance of organisms at the times when system demand allowed operation of the circulating water pumps at reduced flow rates.

Three types of variable flow technologies were considered for retrofit application on the Units 6 and 7 pumps, variable frequency drive (VFD), variable vanes, and multiple speed drive. VFD was selected as the preferred choice, based on experience of application, complexity of operation, and availability of suppliers. A VFD modification would consist of replacement of the existing pumps and motors with new pumps and heavy duty motors with an upgraded motor cooling system as well as a new VFD unit for each pump. The VFD unit varies the frequency of electrical current to the pump motor, and therefore its rotational speed, based on the flowrate required.

The estimated total installed additional[9] capital cost of the VFD modifications for the four cooling water pumps at Units 6 and 7, including new pumps, new motors and four new VFD units is approximately $3.6 million.

Reduction of cooling water flow during reduced load operation will decrease the thermodynamic efficiency of the steam cycle due to higher condenser outlet temperatures, which will result in less power generation for a fixed fuel firing rate. Reduction of cooling water flow is also limited to the extent that the condenser tubes need to be flooded with cooling water for proper operation of the steam turbine generators.

Based on the likely marginal entrainment/impingement benefits due to the limitations for reducing cooling water flow at reduced loads for Units 6 and 7, the significant capital investment required, and generation efficiency penalty, the variable flow alternative is not considered further.

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[9] As described in the project AFC, the existing Units 6 and 7 cooling water pumps have deteriorated due to age and will be replaced as part of the proposed project. It is presently planned to replace the existing pumps with new conventional constant flow pumps. The cost indicated here is the <u>incremental</u> cost to install new VFD pumps instead of the new constant flow pumps.

7.3.5 Dredging the Intake Area

Sediment deposition during normal operation of the cooling water systems of the Moss Landing Power Plant gradually occurs in Moss Landing Harbor in front of the plant and adjacent to the area of the intake bar rocks. Past sediment deposition has caused a decrease in the cross-sectional area of the intake forebays and a corresponding increase in intake approach velocities. Periodic dredging of the intake area as needed is expected to reduce intake velocities and thus the potential number of fishes impinged, and to increase the operational efficiency of the pumps.

The MLPP has instituted a regular program of intake velocity measurement to determine when dredging is needed in front of the cooling water intakes to decrease approach velocities. Intake velocity measurements are taken at least annually and corrective dredging scheduled as needed. Since this program is ongoing and will be expanded to include the new CC units intake in the future, no further consideration of dredging is warranted.

7.3.6 Alternative Biofouling Treatment Schemes

Chlorination and heat treatment are currently used at the MLPP in an effort to control slime accumulation on condenser surfaces and colonization of the cooling water systems by macroinvertebrates such as barnacles, mussels, and hydroids.

Data from the 1979 intra-cooling-system mass balance study at Units 1 through 5 (Table 3-5 of PG&E, 1983) suggest that substantial losses of entrained larval fishes by macroinvertebrates may have occurred in this cooling water intake conduit prior to the retirement of those units. This predation probably occurred because, historically, it was only possible to remove macroinvertebrates through heat treating in the portion of the intake system from the pumpwell to the condensers. Colonizing organisms were not regularly removed in approximately 350 feet of intake conduit between the pumpwell and the shoreline.

Heat treatment of the Units 6 and 7 cooling water system, accomplished by recirculation of warm condenser outlet water, is used to control macroinvertebrates between the condenser outlet gates and the intake inlet gates. Equipment included in the heat treatment involves the inlet tunnel from the inlet gates to the condenser outlet gates, circulating water pumps and traveling screens.

The current NPDES Permit requires the following biofouling controls: “For Units 6 and 7 (discharge 002), heat treatments will be conducted approximately once every one to four months in each of the four conduits.” In addition, “the maximum temperature of the discharge shall not exceed the natural temperature of the intake water by more that 40° F (22.2° C).” At a minimum, twelve heat treatments are conducted a year with the maximum being 48 a year. At the minimum of 12 heat treatments per year, at a maximum temperature of 40° F above the natural temperature of the intake for two hours, the discharge will be impacted with 24 hours a year of 40° F above the natural temperature of the intake and at 48 heat treatments the impact will be 96 hours.

In addition to heat treatment, 14 –16 wt percent sodium hypochlorite (bleach) solution is injected periodically into the circulating water tunnels just after the traveling screens for control of micro-fouling (microscopic algae and bacteria growth) on condenser surfaces. The current dosage at Units 6 and 7 is approximately 20 minutes per tunnel three times per day for a total of approximately 60 minutes per day per tunnel. Residual chlorine levels at the discharge are less than 0.2 mg/l as required by the NPDES permit.

Treatment periods and frequencies for the new combined-cycle units will be similar to those used for Units 6 and 7 with the possibility of some dosage adjustments as necessary when the units come on line. It is currently planned to inject hypochlorite solution at the inlet to the new CC condensers rather than at the suction of the cooling water pumps as currently practiced for Units 6 and 7.

As described in Section 2, the proposed modifications to the existing Units 1 through 5 intake system to accommodate the new CC units include internal structural changes to allow heat treatment of the entire cooling water supply conduit system from the shoreline intake to the condenser inlet. It is expected that the heat treatment procedures and schedules for the new CC units cooling water system will be similar to those currently used for Units 6 and 7. This new heat treatment capability for the entire length of inlet conduit should correct the observed entrainment losses during the historic operation of Units 1 through 5 and further consideration of alternate biofouling controls is not warranted at this time.

7.4 Summary and Conclusions

The preliminary biological benefits, costs, and engineering constraints of the alternative intake technologies considered in Section 7.3 are summarized below. On the basis of this information, a recommendation is made as to the best intake technology available for the new combined-cycle units.

An examination was made of the relative effect of operation of the plant's cooling water system on fish and macroinvertebrate populations. As the field studies of intake effects near completion, no evidence has been found to indicate that cooling water system operations of the new combined-cycle and existing MLPP generating units will result in an adverse impact on the populations of fish and invertebrates inhabiting Moss Landing Harbor, Elkhorn Slough, and Monterey Bay. Most of the organisms entrained and impinged were species that are distributed widely by both ocean currents in Monterey Bay and along the Pacific coast, and by the large tidal exchange in Moss Landing Harbor-Elkhorn Slough. The broad extent and movement of these species along the coast reduces the risk of localized population effects. In addition, the species whose larvae are entrained typically have very high natural mortality rates. The overwhelming majority of the numbers of fish larvae entrained to date is represented by species of no commercial or recreational value. None of the entrained or impinged species are protected or of special concern.

For these reasons, it was concluded at this time that the impact of the existing and proposed modernized Moss Landing Power Plant's operation on marine life has been and will continue to be undetectable, and that there is no certainty that implementation of alternative intake technologies designed to further reduce entrainment or impingement mortality would result in a detectable increase in population abundance for fish and invertebrate species inhabiting the Monterey Bay region and the adjacent coastal waters. The recommendations and discussion of alternative intake technologies presented here are based in part on this conclusion.

7.4.1 Discussion

Alternative intake technologies considered for the new CC units include:

1. seasonal curtailment of cooling system operation,
2. closed-cycle cooling systems,
3. fish collection modifications of the proposed intake screens, and screenwash sluiceway return system,
4. reductions in circulating water flow rates,
5. periodic dredging of the intake area; and
6. alternative biofouling control schemes.

Each of these alternatives is expected to offer some potential for reducing the losses of organisms by entrainment and/or impingement.

Curtailment of cooling system operation would result in reductions of both entrainment and impingement losses. The level of reduction would depend on the abundance of organisms present during the period of curtailment and the duration of the curtailment. The economic consequences of this alternative are so severe that Duke Energy would probably abandon the CC units project. This scenario would result in the associated impacts of higher cost and less reliable electricity for California consumers and increased operation of Units 6 and 7, which require significantly more cooling water per MW-hr generated, and have greater marine impacts, than the proposed CC units. Therefore, curtailment of power plant operation as a method of reducing entrainment and impingement is not a feasible alternative.

Closed-cycle cooling options (mechanical draft cooling towers, natural draft cooling tower, and air cooled condensers) were eliminated on the basis of unacceptable environmental impacts and construction and operating costs. Drift droplets and solids “raining” out of the cooling tower plumes could cause a nuisance liquid deposition on the surrounding area and significant additional particulate emissions. Potential impacts to local agriculture and equipment would occur from deposition of these drift salts. Mechanical draft cooling towers and air cooled condensers are a significant potential source of overall power plant noise impacts on surrounding areas. All three closed-cycle alternatives significantly reduce plant output due, primarily, to reduced steam turbine generator efficiency, and, secondarily, to increased internal plant loads. Likewise, all three options would result in significant visual impacts, particularly the natural draft tower. For all the above reasons, the proposed once-through cooling water system is preferred to a closed-cycled cooling systems.

Modifications of the proposed inclined traveling screens for the refurbished shoreline intake structure to include vertical traveling screens, fish buckets, a low-pressure spraywash system and gravity screenwash sluiceway, with provisions for continuous rotation have the potential for increasing impingement survival of surfperch and rockfish. Impingement survival of species such as northern anchovy and topsmelt probably would not be improved by use of modified intake screens. Incorporation of screen modifications and a fish return system in the new CC units intake could reduce impingement mortality up to 10 percent based on the percent composition of recoverable, impinged species. Additional mortality resulting from passage through the fish return system, including increased susceptibility to disease and predation at the sluiceway discharge, would reduce the expected biological benefits of this alternative. The estimated incremental capital cost of modifying the intake screens to include fish-handling facilities would be approximately $2.6 million (1999 dollars) more than the proposed inclined traveling screen system. Neither the additional indirect O&M costs nor the costs of engineering studies that would be needed to ensure reliable intake screen performance under periodic high detrital loading were quantified, because of a lack of industry-wide experience with modified intake screens under such conditions. Consideration would also need to be given to the potential aesthetic problem, both visual and of odor, created by return of organisms that did not survive impingement to the confines of Moss Landing Harbor. Because of the low impact of impingement losses and the relatively high costs involved, installation of these modified intake screens and fish return for the new CC units is not recommended.

Reduction in circulating water pump operation to coincide with periods of reduced electrical generation or when a unit is out of service has also been identified as a biologically effective method of reducing the losses of organisms through entrainment and impingement. The Moss Landing Power Plant can be operated at reduced loads with less than full circulating water flow, either through removing pumps from service or through installation of variable-speed motor controls. Reducing cooling water flow during extended unit outages is standard operation at the plant and will be practiced for the new CC units. The estimated incremental installed capital cost of variable speed motors and controls for Units 6 and 7, in addition to the upgrades already proposed in the project, is about $4 million. This cost is considered to be disproportionate to the potential benefits resulting from a reduction in entrainment cropping and impingement losses because of the low impact of the present mode of cooling system operation.

Periodic dredging of the intake area to reduce approach velocity is believed to indirectly reduce the impingement rate for fishes. No reduction in entrainment or impingement of macroinvertebrates is expected. Because sediment accumulates in the vicinity of the intakes, the area is periodically dredged as part of the standard operation of the plant and will be continued after installation of the new CC units.

The modifications of the Units 1 through 5 intake system to serve the new CC units will include a design improvement to enable heat treating the entire length of the intake conduit, rather than just a fraction as was the case during previous operation of Units 1 through 5. This improvement will reduce the numbers of biofouling organisms lining the conduits and therefore reduce the number of entrained fish and crab larvae preyed upon by these fouling organisms under the previous operating conditions.

Alternative chemical biocides, application of toxic coatings, and routine mechanical cleaning are not considered to be effective alternative biofouling control techniques.

7.4.2 Conclusions

The proposed new combined-cycle units CWIS design represents the best technology available. This conclusion is based on the preliminary finding of relatively insignificant entrainment and impingement effects and consideration of various demonstrated alternative technologies, including potential biological effectiveness for further reducing entrainment and impingement losses, engineering feasibility, and cost-effectiveness, as outlined in the guidance manual (EPA, 1977).

Intake modifications associated with the combined-cycle modernization will improve the previously experienced environmental impacts of the existing intake structure. New shoreline traveling screens will be installed to significantly reduce the entrapment (and subsequent impingement/entrainment) which formerly occurred in the 350-foot intake tunnel between the intake structure and previous screen location. Additional modifications will allow the heat treatment for biofouling/predator organism removal in the entire cooling water supply conduit. Based on impingement rates reported at the neighboring Units 6 and 7 CWIS, these modifications to the combined-cycle CWIS are expected to significantly reduce the CWIS previously observed impingement rates associated with operating Units 1 through 5.

It is recommended that the present operating practices of (1) reducing the operation of the circulating water pumps when a unit is out of service for an extended period, and (2) periodic intake dredging to reduce sediment accumulation and thereby reduce intake velocities, be continued after installation of the new CC units.

8.0 REFERENCES

Alden Research Laboratories and Stone & Webster Engineering Corporation (ARL/S&W). Laboratory evaluation of fine-mesh screening for fish larvae exclusion at intakes. Research Report EP 8-6, prepared for Empire State Electric Energy Res. Corp. 1980.

Alderdice, D.F. and F.P.J. Velson. Some effects of salinity and temperature on early development of Pacific herring (*Clupea pallasi*). J. Fish Res. Board Can. 28(10):1545-1562. 1971.

Ally, J.R.R. A description of the laboratory-reared larvae of *Cancer gracilis* Dana, 1852 (Decapoda, Brachyura). Crustaceana 23:231-246. 1975.

Ambrose, R.F. Food preferences, prey availability and diet of *Octopus bimaculatus* Verrill. J. Exp. Mar. Biol. Ecol. 77:29-44. 1984.

Anderson, W.R. and R.F. Ford. Early development, growth and survival of the yellow crab *Cancer anthonyi* Rathbun (Decapoda, Brachyura) in the laboratory. Aquaculture 7:267-279. 1976.

Applied Science Associates (ASA). Ichthyoplankton Monitoring Study Deployment of a Gunderboom System at Lovett Generating Station Unit 3, 1998. Orange and Rockland Utilities, Inc. 1999.

Barlow G. W. Intra- and interspecific differences in rate of oxygen consumption in gobiid fishes of the genus *Gillichthys*. Biol. Bull. Mar. biol. Lab., Woods Hole. 121:220-229. 1961.

Barlow, G. W. Species structure of the gobiid fish *Gillichthys mirabilis* from coastal sloughs of the eastern Pacific. Pacific Science. 17:47-72. 1963.

Barlow, G. W. and V. D. De Vlaming. Ovarian cycling in longjaw gobies, *Gillichthys mirabilis*, from the Salton Sea. California Department of Fish and Game, Fish Bull. 58(1):50-57. Sacramento, CA. 1972.

Benech, S.V. Observations of the southern sea otter *Enhydra Lutris* population between Point Buchon and Rattlesnake Creek, San Luis Obispo, California- January through December 1985. In D. W. Behrens and C.O. White, eds. Environmental investigations at Diablo Canyon, 1985. Pacific Gas and Electric Company, San Ramon, California. 1986.

Bengeyfield, W. Evaluation of an Electrical Field to Divert Coho Salmon Smolts from the Penstock Intake at Puntledge Generating Station. Prepared by Global Fisheries Consultants Ltd for B.C. Hydro, Vancouver, B.C. 1990.

Bolin, R.L. A review of the myctophid fishes of the Pacific coast of the United States and of lower California. Stanford Ichthyol. Bull. 1(4): 89-156. 1936.

Boreman, J. Impacts of Power Plant Intake Velocities on Fish. U.S. Fish and Wildlife Service Publication FWS/OBS-76/20.1. 11 pp. 1977.

Boreman, J., C.P. Goodyear, and S.W. Christensen. An Empirical Transport Model for Evaluating Entrainment of Aquatic Organism by Power Plants. United States Fish and Wildlife Service. FWS/OBS-78/90, Ann Arbor, MI. 1978.

Boreman, J., C.P. Goodyear, and S.W. Christensen. An Empirical Methodology for Estimating Entrainment Losses at Power Plants Sited on Estuaries. Transactions of the American Fishery Society. 110:253-260. 1981.

Boulding, E.G. Crab-resistant features of shells of burrowing bivalves: decreasing vulnerability by increasing handling time. J. Exp. Mar. Biol. Ecol. 76:201-223. 1984.

Boulding, E.G. and M. LaBarbera. Fatigue damage: repeated loading enables crabs to open larger bivalves. Biol. Bull. 171:538-547. 1986.

Brewer, G.D. Reproduction and spawning of the northern anchovy, *Engraulis mordax*, in San Pedro Bay, California. California Department of Fish and Game. 64(3): 175-184. 1978.

Brewer, G.D., and G.S. Kleppel. Diel Vertical Distribution of Fish Larvae and Their Prey in Nearshore Waters of Southern California. Marine Ecology Progress Series. 27:217-228. 1986.

Brothers, E. B. The comparative ecology and behavior of three sympatric California gobies. Ph.D. Thesis, University of California at San Diego. 1975.

Brown, R. E. The Potential of Strobe Lighting as a Cost-effective Means for Reducing Impingement and Entrainment. Proceeding of the EPRI/DOE Power Generation Impacts on Aquatic Resources Conference, Atlanta, GA (April 1999). 1999.

Butler, T.H. Growth and age determination of the Pacific edible crab *Cancer magister*. Dana. J. Fish Res. Board Can. 18:873-891. 1961.

California Department of Fish and Game. (CDFG) Annual Landing Summaries. 1979-1998.

California Department of Fish and Game. 1999. (CDFG) http://www.delta.dfg.ca.gov/baydelta/monitoring/baygoby.html

California Department of Fish and Game. 1999. (CDFG). http://www.delta.dfg.ca.gov/baydelta/monitoring/cnigri.html

Carpelan, L. H. Tolerance of the San Francisco topsmelt, *Atherinops affinis affinis*, to conditions in salt-producing ponds bordering San Francisco Bay. California Department of Fish and Game. 41(4):279-284. 1955.

Carroll, J.C. Seasonal abundance, size composition, and growth of rock crab, *Cancer antennarius* Stimpson, off central California. J. Crust. Biol. 2:549-561. 1982.

Carroll, J.C. and R. Winn. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest) Brown Rock Crab, Red Rock Crab, and Yellow Crab. U. S. Fish Wildl. Serv. Biol. Rep. 82 (11.117). U.S. Army Corps of Engineers, TR EL-82-4. 16 pp. 1989.

Chace F.A. Jr. and D.P. Abbott. Caridea: The shrimps. Pages 567-576 *in* R.H. Morris, D.P. Abbott, and E.C. Haderlie, eds. Intertidal invertebrates of California. Stanford University Press, Stanford, Calif. 1980.

Cohen, A. N., Carlton, J. T. and M. Fountain. Introduction, dispersal and potential impacts of the green crab *Carcinus maenas* in San Francisco Bay, California. Mar. Biol. 122: 225-237. 1995.

Cohen, A. N. and J. T.Carlton. Nonindigenous aquatic species in a United States Estuary: A Case Study of the Biological Invasions of the San Francisco Bay and Delta. NOAA. December 1995.

Consolidated Edison Company of New York, Inc. Evaluation of Underwater Sound to Reduce Impingement at the Arthur Kill Station. 1994.

Dahlstrom, W.A. and P.W. Wild. Life history, environment, and mariculture studies of the Dungeness crab, Cancer magister, with emphasis on the central California fishery resource. Department of Fish and Game, Bulletin 172, p. 7. 1983.

De Vlaming, V. L. Thermal selection behavior in the estuarine goby, *Gillichthys mirabilis* Cooper. J. Fish Biol. 3: 277-286. 1971.

Dunning, D. Ultrasound Deterrence: Alewife at a Nuclear Generating Station in New York. 1995. *In* T. J. Carlson and A. N. Popper (eds.): Using Sound to Modify Fish Behavior at Power-Production and Water-Control Facilities: A Workshop. Prepared for U.S. Department of Energy and Bonneville Power Administration, DOE/BP-62611-11. 1994.

Ebert, E.E. and C. H. Turner. The nesting behavior, eggs and larvae of the bluespot goby. California Department of Fish and Game. 48(4) 1962.

Ecological Analysts, Inc. (EA). Unpublished. Observations made during fishery and ichthyoplankton collections made at five California coastal power plants. 1978-1981.

Ecological Analysts, Inc. (EA). Evaluation of the effectiveness of a continuously operating fine mesh traveling screen for reducing ichthyoplankton entrainment at the Indian Point Generating Station. Prepared for Central Hudson Gas & Electric Corporation, Consolidated Edison Company of New York, Inc., Orange and Rockland Utilities, Inc., and Power Authority of the State of New York. 1979.

Ecological Analysts, Inc. (EA). Evaluation for the potential to reducing losses of striped bass at the Pittsburg and Contra Costa Power Plants by Reducing Intake Velocities. Prepared for PG&E 77 Beale Street, San Francisco, 28 pp. Plus 4 pp. Attachment. 1982.

Ecological Analysts, Inc. (EA). Moss Landing Power Plant Units 1-5 316(a) demonstration supplement: distribution and abundance of ichthyoplankton and macrozooplankton in Moss Landing Harbor and Elkhorn Slough. Prepared for Pacific Gas and Electric Company, San Francisco. 1982.

Eicher, G. J. Adaptation of hydro fish facilities to steam-electric stations, *In* Proceedings of the second workshop on entrainment and intake screening (L. D. Jensen, ed.), pp. 273-276. EPRI Publ. 74-049-00-5. Electric Power Research Institute, Palo Alto, California. 1974.

Eldridge, M.B. Factors influencing distribution of fish eggs and larvae over eight 24-hour samplings in Richardson Bay, California. California Department of Fish and Game. 63(2):101-116. 1977.

Electric Power Research Institute. Evaluation of Fish Behavioral Barriers. EPRI Report No. TR-109483. 1998.

Emmett, R.L., S.L. Stone, S.A. Hinton, and M.E. Monaco. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume II: species life hisory summaries. ELMR Rep. No. 8. NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD, 329 p. 1991.

EPA. Development Document for Best Technology Available for the Location, Design, Construction, and Capacity of Cooling Water Intake Structures for Minimizing Adverse Environmental Impact. EPA-440/1-76/015a. 263 pp. 1976.

EPA. Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: Section 316(b) P.L. 92-500. 58 pp. 1977.

Eschmeyer, W. N., E. S. Herald, and H. Hamann. A Field Guide to Pacific Coast Fishes of North America. Peterson Field Guide Series. Houghton Mifflin Co., Boston, MA. 1983.

Fierstine, H. L., K. F. Kline, G. R. Garman. Fishes collected in Morro Bay, California between January, 1968 and December, 1970. California Department of Fish and Game. 59(1): 73-78. 1973.

Fish and Wildlife Information Exchange. (FWIE). Department of Fisheries and Wildlife Sciences. Virginia Tech. 1999. http://fwie.fw.vt.edu/WWW/macsis/lists/M070013.htm. 1999.

Fitch, J.E. and R.J. Lavenberg. Tidepool and nearshore fishes of California. University of California Press, Berkeley. 156 pp. 1975.

Frey, H.W., ed. California's living marine resources and their utilization. California Department of Fish and Game. 148pp. 1971.

Fried, S.M. and V.G. Wespestad. Productivity of Pacific herring (*Clupea harengus pallasi*) In the eastern Bering Sea under various patterns of exploitation. Can. J. Fish. Aquat.Sci. 42 (Suppl. 1):181-191. 1985.

Fuller, P., 1999. http://nas.er.usgs.gov/fishes/accounts/gobiidae/gi_mirab.html

Fuzessery Z.M. and J.J. Childress, Comparative chemosensitivity to amino acids and their role in feeding activity of bathypelagic and littoral crustaceans. Biol. Bull. 148:522-538. 1975.

Garth, J.S. and D.P. Abbott. Brachyura: the true crabs. Pages 594-630 in R.H. Morris, D.P. Abbott, and E.C. Haderlie, eds. Intertidal invertebrates of California. Stanford University Press, Stanford, Calif. 1980.

Goodyear, C.P. Entrainment Impact Estimates Using the Equivalent Adult Approach. U.S. Fish and Wildlife Service, FWS/OBS-78/65, Ann Arbor, MI. 1978.

Gotshall, D.W. Stomach contents of Northern California Dungeness crabs *Cancer magister*. Calif. Fish Game 63:43-51. 1977.

Graham, W.M. The influence of hydrography on the larval dynamics and recruitment of five *Cancer* crab species in northern Monterey Bay. M.S. Thesis, University of California, Santa Cruz. 170 pp. 1989.

Gray, C.A. Horizontal and Vertical Trends in the Distributions of Larval Fishes in Coastal Waters Off Central New South Wales, Australia. Marine Biology. 116:649-666. 1993.

Gray, C.A. Diel Changes in Vertical Distributions of Larval Fishes in Unstratified Coastal Waters Off Southeastern Australia. Journal of Plankton Research. 20(8):1539-1550. 1998.

Grosholz, E. D. and G. M. Ruiz. Spread and potential impact of the recently introduced European green crab, *Carcinus maenas*, in central California. Mar. Biol. 122: 239-247. 1995.

Grosholz, E.D. Green Crabs Attack. Native Species Network. UC Davis Bodega Marine Laboratory. 1996. http://www.ncal.verio.com/~nsn/nsngrncrb.html

Grossman, G. D. Demographic characteristics of an intertidal bay goby (*Lepidogobius lepidus*). Env. Biol. Fish. 4(3): 207-218. 1979.

Gunderson, D. R. and P.H. Dygert. Reproductive effort as a predictor of natural mortality rate. J. Cons. Cons. Int. Explor. Mer. 44:200-209. 1988.

Hardwick, J.E. Biomass estimates of spawning herring. *Clupea harengus pallasii*, Herring eggs, and associated vegetation in Tomales Bay. California Department of Fish and Game. 59(1):36-61. 1973.

Hart, J. L. Pacific Fishes of Canada. Fisheries Research Board of Canada, Bull. 180: 366-367. 1973.

Hay, D.E. Reproductive biology of Pacific herring (*Clupea harengus pallasi*). Can. J. Fish. Aquat. Sci 42(Suppl. 1):111-126. 1985.

Heimann R.F.G. and J.G. Carlisle. The California marine fish catch for 1968 and historical review 1916-68. Calif. Dep. Fish Game, Fish Bull. No. 149. 70 pp. 1970.

Hewitt, R.D. Spatial pattern and survival of anchovy larvae: implications of adult reproductive strategy. Ph.D. Thesis, Univ. of California, San Diego. 207 pp. 1982.

Hewitt, R.D., and R.D. Methot. Distributions and mortality of northern anchovy larvae in 1978 and 1979. CalCOFI Rept. 23:226–245. 1982.

Hewitt, R.D., and G.D. Brewer. Nearshore production of young anchovy, CalCOFI Rept. 24:235-244. 1983.

Hochberg, F.G. Jr. and W.G. Fields. Cephalopoda: The Squids and Octopuses. Pages 429-444 *in* R.H. Morris, D.P. Abbott, and E.C. Haderlie, eds. Intertidal invertebrates of California. Stanford University Press, Stanford, Calif. 1980.

Horst, T.J. The Assessment of Impact Due to Entrainment of Ichthyoplankton in S.B. Saila (ed.) Fisheries and Energy Production: A Symposium. Lexington Books, D.C. Health and Company, Lexington, MA. pp. 107-118. 1975.

Hourston, A.S. and C. W. Haegele. Herring on Canada's Pacific Coast. Can. Spec. Publ. Fish. Aquat. Sci 48. 1980.

Hsueh, Pan-Wen. Seasonal Occurrence and Abundance of Brachyuran Larvae in a Coastal Embayment of Central California. Journal of Crustacean Biology. 11(4): 546-552. 1991.

Humann, P. Coastal Fish Identification: California to Alaska. New World Publications Inc., Jacksonville, FL, U.S.A. pp. 176-177. 1996.

Jacobson, L. D., N.C.H. Lo, S.F. Herrick, Jr., and T. Bishop. Spawning biomass of the northern anchovy in 1995 and status of the coastal pelagic fishery during 1994. SWFC/NMFS. 50 pp. 1995.

Jacobson, L. D., N.C.H. Lo, and M. Yaremko. Status of the northern anchovy (*Engraulis mordax*) stock (central population) during the 1996-1997 season. SWFC/NMFS Admin. Rept. LJ-97-08. 11 pp. 1997.

Jensen, G.C. Pacific coast crabs and shrimps. Sea Challengers, Monterey, California. 1995.

Jones, A.C. The biology of the euryhaline fish *Leptocottus armatus armatus* Girard (cottidae). Univ. Calif. Publ Zool. 67(4):321-367. 1962.

Knudsen, F. R., P. S. Enger, and O. Sand. Awareness Reactions and Avoidance Responses to Sound in Juvenile Atlantic Salmon, *Salmo salar* L. Journal of Fish Biology. 40:523-534. 1992.

Knudsen, F. R., P. S. Enger, and O. Sand. Avoidance Responses to Low Frequency Sound in Downstream Migrating Atlantic Salmon, *Salmo salar* L. Journal of Fish Biology. 45:227-233. 1994.

Krebs, C.J. Ecological Methodology. Harper & Row, New York. 65 pp. 1989.

Krygier, E.E. and H.F. Horton. Distribution, reproduction and growth of *Crangon nigricauda* and *Crangon franciscorum* in Yaquinq Bay, Oregon. Northwest Sci. 49(4):216-240. 1975.

Kynard, B. and J. O'Leary. Behavioral Guidance of Adult American Shad Using Underwater AC Electrical and Acoustic Fields. Proceedings of the International Symposium on Fishways '90. October 8-10, Gifu, Japan, pp. 131-135. 1990.

Lawler, Matusky & Skelly Engineers (LMS). 1996a. Effectiveness Evaluation of a Fine Mesh Barrier Net Located at the Cooling Water Intake of the Bowline Point Generating Station. Prepared for Orange and Rockland Utilities, Inc. 1996.

Lawler, Matusky & Skelly Engineers (LMS). 1996b. Lovett Generating Station Gunderboom Evaluation Program 1995. Orange and Rockland Utilities, Inc. LMSE-96/0291&169/330. 1996.

Lawler, Matusky & Skelly Engineers (LMS). Lovett Generating Station Gunderboom Evaluation Program 1996. Orange and Rockland Utilities, Inc. LMSE-97/0191&169/321. 1997.

Lawler, Matusky & Skelly Engineers (LMS). Lovett Generating Station Gunderboom Evaluation Program 1998. Orange and Rockland Utilities, Inc.169-335. 1998.

Leet, W.S., C.M. Dewees and C.W. Haugen, eds. California's living marine resources and their utilization. Sea Grant Extension Publication. UCSGEP-92-12. 1992.

Lindquist, D.C. The Effects of Erosion on the Trophic Ecology of Fishes in Elkhorn Slough, CA. Unpublished Master's Thesis. Moss Landing Marine Laboratories, Moss Landing, CA. 65 pp. 1998.

Lo, N.C.H. Re-estimation of three parameters associated with anchovy egg and larval abundance: Temperature dependent hatching time; yolk-sac growth rate; and egg and larval retention in mesh nets. U.S. Dept of Comm., NOAA NMFS SWFC-31, 38pp. 1983.

Lo, N.C.H. Egg production of the central stock of northern anchovy 1951–1983. Fish. Bull. 88:137–150. 1985.

Lo, N.C.H. Modeling life-stage-specific instantaneous mortality rates, an application to northern anchovy, *Engraulis mordax*, eggs and larvae. Fish. Bull. 84(2):395-407. 1986.

Love, M. Probably more than you want to know about the fishes of the Pacific Coast. (2nd ed.). Really Big Press. pp. 303-304. Santa Barbara, California. 1996.

Love, M.S., G.E. McGowen, W. Westphal, R.J. Lavenberg, and L. Martin. Aspects of the life history and fishery of the white croaker, *Genyonemus lineatus* (Sciaenidae), *In* California. Fish. Bull., U.S. 82:179-198. 1984.

MacCall, A.D., K.R. Parker, R. Leithiser, and B. Jessee. Power Plant Impact Assessment: A Simple Fishery Production Model Approach. Fishery Bulletin. 81(3):613-619. 1983.

Malzone, C. Tidal Scour and its Relation to Erosion and Sediment Transport in Elkhorn Slough. Masters Thesis. San Jose State University. CA. 1999.

Malzone, C., and R. Kvitek. Tidal Scour, Erosion, and Habitat Loss in Elkhorn Slough, CA. Report of the Elkhorn Slough Foundation to the National Oceanic and Atmospheric Administration. Award #NA370M0523. 1994.

Matarese, A. C., A. W. Kendall Jr., D. M. Blood and B. M. Vintner. Laboratory Guide to Early Life History Stages of Northeast Pacific Fishes. NOAA Technical Report NMFS 80, 652 pp. 1989.

McGowan, J.A. and D.M. Brown. A New Opening-Closing Paired Zooplankton Net. Univ. Calif. Scripps Inxt. Oceanogr. Ref. 66-23, pp. 1-56. 1966.

Michaud, D. T. and E. P. Taft. Recent Evaluation of Physical and Behavioral Barriers for reducing Fish Entrainment at Hydroelectric Projects in the Upper Midwest. Proceeding of the EPRI/DOE Power Generation Impacts on Aquatic Resources Conference, Atlanta, GA (April 1999). 1999

Miller, D. J. and Lea, R. N. Guide to the Coastal Marine Fishes of California. California Department of Fish and Game Fish Bulletin. 157:188. Sacramento, CA. 1972.

Miller, D.J. and J. Schmidtke. Report on the distribution and abundance of Pacific herring (*Clupea pallasi*) along the coast of Central and Southern California. California Department of Fish and Game. 42(3):163-187. 1956.

Morris, R.W. Early larvae of four species of rockfish, Sebastodes. Calif. Fish and Game, vol. 42(2):149-153.1956.

Moser, H. G. The Early Stages of Fishes in the California Current Region. California Cooperative Oceanic Fisheries Investigations, Atlas No. 33; 1214-1226. Allen Press Inc., Lawrence, Kansas. 1996.

Moser, H.G., and P.E. Smith. Larval Fish Assemblages in the California Current Region and their Horizontal and Vertical Distribution Across a Front. Bulletin of Marine Science. 53(2):645-691. 1993.

Moyle, P.B. Inland fishes of California. University of California Press, Berkeley. 405 pp. 1976.

Moyle, P.B. and Cech. Fishes: An Introduction to Ichthyology. Department of Wildlife and Fisheries Biology, U.C. Davis. Prentice Hall, Englewood Cliffs, New Jersey, 07632. pp. 46, 121, 304, 305, 426. 1988.

Murdoch, W.W., R.C. Fay, and B.J. Mechalas. Final Report of the Marine Review Committee to the California Coastal Commission, MRC Doc. No. 89-02, 346 pp. 1989.

Nelson, J. S. Fishes of the world, third edition. John Wiley & Sons, New York. 600 pp. 1994.

Nybakken, J. W., G. M. Cailliet and W. W. Broenkow. Ecologic and hydrographic studies of Elkhorn Slough, Moss Landing Harbor, and near-shore coastal waters, July 1974 to June 1976. Moss Landing Marine Laboratories, Moss Landing, California. 1977.

Odenweller, D. B. The life history of the shiner surfperch *Cymatogaster aggregata Gibbons*, in Anaheim Bay, California. CDFG Fish Bull. 165, The Marine Resources of Anaheim Bay. pp 107-115. 1975.

Orensanz, J.M. and V. F. Gallucci. Comparitive study of postlarval life-history schedules in four sympatric species of *Cancer* (Decapoda: Brachyura: Cancridae). Journal of Crustacean Biology, 8(2):187-220. 1988.

Oxman, D.S. Seasonal abundance, movements, and food habits of harbor seals (*Phoca vitulina richardsi*) in Elkhorn Slough, California. MLML Thesis. 1995.

Pacific Fish Management Council (PFMC). Sixth Amendment to the Northern Anchovy Fishery Management Plan. Portland, OR. 68 pp. 1990.

Pacific Fishery Management Council (PFMC). Amendment 8 (to the Northern Anchovy Fishery Management Plan) incorporating a name change to: The Coastal Pelagic Species Fishery Management Plan. Portland, Oregon. 1998.

Pacific Gas and Electric Company (PG&E). An evaluation of the effect of cooling water discharges on the beneficial uses of receiving waters at Moss Landing Power Plant. Mimeo. PGandE, San Francisco. 1973.

Pacific Gas and Electric Company (PG&E). Moss Landing Power Plant Units 1-5 316(a) demonstration. PGandE, San Francisco. 1978.

Pacific Gas and Electric Company (PGandE). Potrero Power Plant cooling water intake structure 316(b) demonstration. Prepared by Ecological Analysts, Inc. PGandE, San Francisco. 1980.

Pacific Gas and Electric Company (PG&E). Impingement Studies at Morro Bay Power Plant. PG&E, Department of Engineering Research, San Ramon, CA. 1982.

Pacific Gas and Electric Company (PG&E). Moss Landing Power Plant Cooling Water Intake Structures 316(b) Demonstration. PG&E, San Francisco, CA. 1983.

Pacific States Marine Fisheries Commission, (PSMFC) 1999. http://www.psmfc.org/habitat/edu_herring_fact.html

Pacific States Marine Fisheries Commission, (PSMFC) 1999. http://www.psmfc.org/Lifehistory/crab_fact.html

Page, H.M., J.E. Dugan, D.S. Dugan, J. Richards, D. Hubbard, Effects of an offshore oil platform on the distribution and abundance of commercially important crab species. Marine Ecol. Progr. Ser. 185:47-57. 1999.

Page, T. L., R. H. Gray and D. A. Neitzel. Fish impingement studies at the Hanford Generating Project, December 1975 through April 1976. Report to Washington Public Power Supply System. Battelle-Northwest, Richland, Washington. 1976.

Page, T. L., D. A. Neitzel and R. H. Gray. Comparative fish impingement (at two adjacent water intakes on the mid-Columbia River). *In* Fourth national workshop on entrainment and impingement (L. D. Jensen-,ed.). pp.257-266. Ecological Analysts, Inc., Sparks, Maryland. 1978.

Paine, R. T. Food recognition and predation on opisthobranchs by *Navanax intermis*. Veliger 6:1-2. 1963.

Parker, D., Rock Crabs. In: Leet, W.S., Dewees, C.W., Haugen, C.W. (eds) California's living marine resources and their utilization. California Sea grant, Sea Grant Extension Publication, Univ. Calif., San Diego, UCSGEP-92-12, p 18-20. 1992.

Parker, K.R. A direct method for estimating northern anchovy, Engraulis mordax, spawning biomass. Fish. Bull., U.S. 78:541-544. 1980.

Parker, K.R. and E. DeMartini. Adult-Equivalent Loss. Technical Report to the California Coastal Commission, Marine Review Committee, Inc. 56 pp. 1989.

Phillips, J. Life history studies on ten species of rockfish. CA Dept. of Fish Game, Fish Bull. 126. 70 pp. 1964.

Philip Williams and Associates, Ltd. Elkhorn Slough Tidal Hydraulics Erosion Study. Prepared for: U.S. Army Corps of Engineers, San Francisco, CA. 85 pp. 1992.

Ploskey G. R., J. M. Nestler, G. N. Weeks, and C. Schilt. Evaluation of an Integrated Fish-Protection System. *In* Waterpower 95, Proceedings of the International Conference on Waterpower. American Society of Civil Engineers, New York, NY. 1995.

Poole, R.L. A description of laboratory-reared zoea of *Cancer magister* Dana, and Megalopae taken under natural conditions (Dedapoda, Brachyura), Crustacean, 11 (2):83-97. 1966.

Public Service Electric and Gas Company. Impingement monitoring program - Salem Nuclear Generating Station Unit No. 1., Report 2., Docket No. 50-272. 1977.

Public Service Electric and Gas Company. Appendix I - Modeling. Permit No. NJ0005622. Prepared by Lawler, Matusky, and Skelly Engineers, Pearl River, NY. Comments on NPDES Draft. 82 pp. 1993.

Reeder, W. G. Stomach analysis of a group of shorebirds. Condor 53:43-45. 1951.

Reider, R. H., D. D. Johnson, P. Brad Latvaitis, J. A. Gulvas, E. R. Guilfoos. Operation and Maintenance of the Ludington Pumped Storage Project Barrier Net. *In* Fish Passage Workshop, Milwaukee, Wisconsin, May 6-8, 1997. Sponsored by Alden Research Laboratory, Conte Anadromous Fish Research Laboratory, Electric Power Research Institute, and Wisconsin Electric Power Company. 1997.

Reilly, P.N. Population studies of rock crab, *Cancer antennarius*, yellow crab *Cancer anthonyi*, and Kellet's welk, *Kelletii kelletii*, in the vicinity of Little Cojo Bay, Santa Barbara County, California. Calif. Fish Game. 73:88-98. 1987.

Reilly, P.N. Dynamics of Dungeness crab, Cancer magister, larvae off central and northern California. Department of Fish and Game, Bulletin 172. 1983

Ricker, W.E. Computation and Interpretation of Biological Statistics of Fish Populations. Fishery Research Board of Canada Bulletin 91. 382 pp. 1975.

Ricketts, E.F., J. Calvin, J.W. Hedgepeth, and D.W. Phillips. Between Pacific tides. 5th ed. Stanford University Press, Stanford, Calif. 652 pp. 1985.

Roberts, D.A., E.E. DeMartini, and K.M. Plummer. The feeding habits of juvenile-small adult barred sand bass *Paralabrax nebulifer* in nearshore waters off northern San Diego County. Calif. Coop. Ocean. Fish. Invest. Rep. 25. 7pp. 1984.

Rumrill, S.S., J.T. Pennington, and F. Chia. Differential suceptibility of marine invertebrate larvae: laboratory predation of sand dollar *Dendraster excentricus* (Eschscholtz) embryos and larvae by zoea of the red crab *Cancer productus* Randall. J. Exp. Mar. Biol. Ecol. 90:193-208. 1985.

Saila, S.B., E. Lorda, J.D. Miller, R.A. Sher, and W.H. Howell. Equivalent Adult Losses of Fish Eggs, Larvae and Juveniles at Seabrook Station with Use of Fuzzy Logic to Represent Parametric Uncertainty. North American Journal of Fishery Management. 17(4):811-825. 1997.

San Filippo, R. Diet, gastric evacuation and estimates of daily ration of the gray smoothhound, mustelus californicus. M.A. thesis, San Jose State University, 70 pp. 1994.

Schiel, D.R., and B.C. Welden. Responses to predators of cultured and wild red abalone, *Haliotis rufescens*, in laboratory experiments. Aquaculture 60:173-188. 1987.

Schlotterbeck, R.E., and D.W. Connally. Vertical Stratification of Three Nearshore Southern California Larval Fishes (*Engraulis mordax, Genyonemus lineatus, and Seriphus politus*). Fishery Bulletin. 80(4):895-902. 1982.

Schweigert, J.F. and A.S. Hourston. Cohort analysis and mortality rates of the Barkley Sound herring stock. 1972-1979. Can. Tech. Rep. Fish. Aquat. Sci. 960. 37 pp. 1980.

Selby, R.S. Some aspects of the ecology and biology of two *Cancer* species. M.S. Thesis. University of Oregon, Eugene. 96 pp. 1980.

Simpson, A.C. The Spawning of Plaice in the North Sea. Fisheries Investigations of the Ministry of Agriculture, Fisheries, and Food of Great Britain 22. 111 pp. 1959.

Skogsberg, T. The fishes of the family Sciaenidae (croakers) of California. California Department of Fish and Game Bulletin 54. 62pp. 1939.

Smith, P.E., R.C. Counts, and R.I. Clutter. Changes in Filtering Efficiency of Plankton Nets Due to Clogging Under Tow. J. Cons. perm. int. Explor. Mer 32(2):232-248. 1968.

Smith, P.E. and S.L. Richardson. Standard Techniques for Pelagic Fish Egg and Larva Surveys. FAO Fisheries Technical Paper 175:1-100. 1977.

Somerton, D. A. A computer technique for estimating the size of sexual maturity in crabs. Canadian Jornal of Fisheries and Aquatic Sciences. 37:1480-1494. 1980.

Starr, R.K., A. Johnson, E.A. Laman, G.M. Cailliet. Fishery Resources of the Monterey Bay National Marine Sanctuary. California Sea Grant College Technical Report NO. T-042, 102 pp. 1998.

Steele, M. A. Population regulation by post-settlement mortality in two temperate reef fishes. Oecologia. 112: 64-74. 1997.

Stephens, J. S., Jr., R. K. Johnson, G. S. Key, and J. E. McCosker. The comparative ecology of three sympatric species of California blennies of the genus *Hypsoblennius* Gill (Teleostomi, Blenniidae). Ecol. Monogr. 40(2):213-233. 1970.

Stevenson, J.C. Distribution and survival of herring larvae (*Clupea pallasi* Valenciennes) in British Columbia waters. J. Fish Res. Board Can. 19(5):735-810. 1962.

Stocker, M., V. Haist, and D. Fournier. Environmental variation and recruitment of Pacific herring (*Clupea harengus pallasi*) in the Strait of Georgia. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):174-180. 1985.

Stone & Webster Engineering Corporation. Ocean-sited plants. Prepared for the Utility Water Act Group. 1978.

Streamnet. 1999. http://www.streamnet.org/ff/Lifehistory/html

Suisun Ecological Workgroup. 1999. (SEW). http://www.iep.water.ca.gov/suisun_eco_workgroup/workplan/report

Svetovidov, A.N. Fauna of the U.S.S.R., Fishes, Vol. 2, No. 1 Clupeidae, originally Published in Russia in 1952. 1963.

Taft, E.P., *Fish Protection Technologies: A Status Report*. In: Power Impacts on Aquatic Resources Conference, Atlanta, GA, April 12-15, 1999. Sponsored by Electric Power Research Institute (EPRI). 1999.

Talent, L.G. Food habits of the gray smoothhound *Mustelus henlei*, the shovelnose guitarfish *Rhinobatis productus*, and the Bat ray *Myliobatis californica* in Elkhorn Slough, California. Calif. Fish Game. 68:224-234. 1982.

Tasto, R.N. Aspects of the biology of Pacific staghorn sculpin, *Leptocottus armatus* Girard, in Anaheim Bay. In the marine resources of Anaheim Bay (E.D. Lane and C.W. Hill, eds.), pp 123-135. California Department of Fish and Game Bulletin 165. 1975.

Tenera Inc. Diablo Canyon 316(b) Sampling Plan and Modelling Evaluation. Prepared for Pacific Gas and Electric Company. San Francisco, CA. 1998.

Tenera, Inc. Final Moss Landing Power Plant Modernization Project Cooling Water Intake and Discharge Study Plans. Prepared for Duke Energy North America. Oakland, CA. 1999.

Tenera, Inc. Diablo Canyon Power Plant 316(b) Demonstration Report. Prepared for Pacific Gas and Electric Company. San Francisco, CA.

Texas Instruments Inc. (Texas Instruments). Initial and extended survival of fish collected from a fine-mesh continuously operating traveling screen at the Indian Point Generating Station for the period 15 June – 22 December 1977. Draft. Prepared for Consolidated Edison Company of New York, Inc., New York. 1977.

Teylaud, A. R. Food habits of the goby, *Ginsburgellus novemlinaetus* and the clingfish, *Acros rubiginosis*, associated with echinoids in the Virgin Islands. Caribb. J. Sci. 11:41-45. 1971.

Thomas, D.H. and J.R. Bence. Bocaccio In: Leet, W.S., Dewees, C.W., Haugen, C.W. (eds) California's living marine resources and their utilization. California Sea grant, Sea Grant Extension Publication, Univ. Calif., San Diego, UCSGEP-92-12, p 18-20. 1992.

Todd, E. S. Terrestrial sojourns of the longjaw mudsucker, *Gillichthys mirabilis*. Copeia 1: 192-194. 1968.

Toole, C.L. Rock crab survey of Humbolt Bay- Interim report. California Sea Grant Marine Advisory Program, Eureka. 14 pp. 1985.

Tranter, D.J. and P.E. Smith. Filtration Performance. In Zooplankton Sampling, D.J. Tranter, Editor, UNESCO Monographs on Oceanographic Methodology 2:27-56. 1968.

Trask, T. A description of laboratory-reared larvae of *C. productus* and comparison to larvae *of C. magister*. Crustaceana 18:133-147. 1970.

Trumble R.J., and R.D. Humphreys. Managemant of Pacific herring (*Clupea harengus pallasi*) in the eastern Pacific Ocean. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):230-244. 1985.

Turner, C.H., E.E. Ebert, and R.R. Given. Man-made reef ecology. Calif. Dep. Fish Game Fish Bull. No. 146. 221 pp. 1969.

University of California Los Angeles. (UCLA) 1999. http://www.lifesci.ucla.edu/odc/html/body_marketsquid.html

Van Blaricom, G.R. Disturbance, predation, and resource allocation in a high-energy sublittoral sand-bottom ecosystem: Experimental analysis of critical structuring processes for the infaunal community. Ph.D. Dissertation. University of California, San Diego. 1978.

Van Blaricom, G.R. Experimental analyses of structural regulation in a marine sand community exposed to oceanic swell. Ecol. Monogr. 52:(3)283-305. 1982.

Walker, B. W., R.R. Whitney, and G.W Barlow. Fishes of the Salton Sea: The ecology of the Salton Sea, California, in relation to the sport fishery of California. California Department of Fish and Game Fish Bulletin. 113: 88-91. Sacramento, CA. 1961.

Wang, J. C. S. Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A Guide to the Early Life Stages. Technical Report 9, January,1986. 1986.

Wang, J.C.S., 1999. http://elib.cs.berkeley.edu/kopec/tr9/html/sp-pacific-herring.html

Washington Department of Fish and Wildlife. (WDFW). 1999. http://www.wa.gov/wdfw/fish/shelfish/greencrb.html

Watson, W. Development of eggs and larvae of the white croaker, *Genyonemus Lineatus* Ayers (Pices: Sciaenidae), off the southern California coast. Fish Bull., U.S. 80:403-417. 1982.

Weisel, G. F. Breeding behavior and early development of the mudsucker, a gobiid fish of California. Copeia 2: 77-85. 1947.

Wild, P.W. and R.N. Tasto. Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Department of Fish and Game, Bulletin 172, p. 319-323. 1983.

Wiley, J. W. Life history of the western North American goby *Coryphopterus nicholsii* (Bean). Trans. San Diego Soc. Nat. Hist. 17(14): 187-208. 1973.

Winn, R.N. Comparative ecology of three cancrid crab species (*Cancer anthonyi, C. antennarius, and C. productus*) in marine subtidal habitats in southern California. Ph.D. Dissertation. University of Southern California, Los Angeles. 235 pp. 1985.

Yoklavich, M.M., G. M. Cailliet, J.P. Barry, D. A. Ambose, B.S. Antrim. Temporal and Spatial Patterns in Abundance and Diversitiy of Fish Assemblages in Elkhorn Slough, California. Estuaries, Vol. 14, No. 4. 1991.

Yoklavich, M.M., M. Stevenson, and G.M. Cailliet. Seasonal and Spatial Patterns of Ichthyoplankton Abundance in Elkhorn Slough, California. Estuarine, Coastal, and Shelf Science 34:109-126. 1992.

Yoklavich, M.M., G. M. Cailliet, D. S. Oxman, J.P. Barry, D.C. Lindquist. Fish Assemblages of Elkhorn Slough and Adjacent Habitats. Draft. 1999.

Zweifel, J.R. and P.E. Smith. Estimates of abundance and mortality of larval anchovies (1951-1975). Rapp. P.-v. Reun. Cons. Int. Explr. Mer. 178:248-259. 1981.

Appendix A

Estimating Total Annual Entrainment

An estimate of total annual larval entrainment at an intake source (i.e., either the new combined-cycle [CC] units or Units 6 and 7) can be expressed as

$$\hat{E} = \sum_{i=1}^{L} \left[\frac{D_i}{d_i} \sum_{j=1}^{d_i} \left[\sum_{k=1}^{4} \frac{V_{ijk}}{2} \sum_{l=1}^{2} x_{ijkl} \right] \right] \tag{A1}$$

where

x_{ijkl} = measured density of larvae in the *l*th tow $(l = 1,2)$ within the *k*th cycle $(k = 1, \ldots, 4)$ on the *j*th day $(j = 1, \ldots, D_i)$ in the *i*th stratum $(i = 1, \ldots, L)$;

V_{ijk} = total water intake during the *k*th cycle $(k = 1, \ldots, 4)$ from the *j*th day $(j = 1, \ldots, D_i)$ in the *i*th stratum $(i = 1, \ldots, L)$;

D_i = number of sampling days in the *i*th stratum of which d_i are sampled (nominally d_i = 2).

Here, a temporal stratum will be defined as a 2- or 4-week period (i.e., depending on time of year) where in 2 days are selected for sampling. Equation (A1) can also be expressed in terms of a volume-adjusted estimate where

$$\hat{E} = \sum_{i=1}^{L} \left[\frac{V_{Ti}}{V_i} \sum_{j=1}^{d_i} \left[\sum_{k=1}^{4} \frac{V_{ijk}}{2} \sum_{l=1}^{2} x_{ijkl} \right] \right] \tag{A2}$$

and where

$$V_i = \sum_{j=1}^{d_i} \sum_{k=1}^{4} V_{ijk} \, ,$$

$$V_{Ti} = \sum_{j=1}^{D_i} \sum_{k=1}^{4} V_{ijk} \, .$$

Nominally, d_i will be 2 days for all temporal stratum. The variance of $\hat{E}$ [i.e., Equation (A2)] can be expressed as

$$Var\left(\hat{E} \middle| E\right) = \sum_{i=1}^{L} \left\{ \left(\frac{V_{Ti}}{V_i} \right)^2 \left[\frac{d_i^2 \left(1 - \frac{d_i}{D_i} \right) S_{E_{ij}}^2}{d_i} + \frac{d_i}{D_i} \sum_{j=1}^{D_i} \sum_{k=1}^{4} V_{ijk}^2 \frac{S_{x_{ijkl}}^2}{2} \right] \right\} \tag{A3}$$

where

$$S^2_{x_{ijkl}} = \frac{\sum_{l=1}^{N_{ijk}} \left(x_{ijkl} - \overline{X}_{ijk}\right)^2}{\left(N_{ijk} - 1\right)};$$

$$\overline{X}_{ijk} = \frac{\sum_{l=1}^{N_{ijk}} x_{ijkl}}{N_{ijk}};$$

N_{ijk} = total number of tows possible during the *k*th cycle $(k = 1, \ldots, 4)$ of the *j*th day $(j = 1, \ldots, d_i)$ in the *i*th $(i = 1, \ldots, L)$ stratum;

and where

$$S^2_{E_{ij}} = \frac{\sum_{j=1}^{D_i} \left(E_{ij} - \overline{E}_i\right)^2}{\left(D_i - 1\right)};$$

E_{ij} = total entrainment during the *j*th day $(j = 1, \ldots, D_i)$ in the *i*th stratum $(i = 1, \ldots, L)$;

$$\overline{E}_i = \frac{\sum_{j=1}^{D_i} E_{ij}}{D_i}.$$

Variance (A3) is based on the assumption that d_i are a random sample from D_i days in the *i*th stratum $(i = 1, \ldots, L)$. The variance also assumes the 2 tow volumes are a random sample of the intake water during the *k*th cycle $(k = 1, \ldots, 4)$ of the *j*th day $(j = 1, \ldots, d_i)$. An unbiased variance estimator can be expressed (Appendix A) as

$$V\hat{a}r\left(\hat{E} \middle| E\right) = \sum_{i=1}^{L} \left\{ \left(\frac{V_{Ti}}{V_i}\right)^2 \left[d_i \left(1 - \frac{d_i}{D_i}\right) s^2_{\hat{E}_{ij}} + \frac{d_i}{D_i} \sum_{j=1}^{d_i} \sum_{k=1}^{4} \frac{V^2_{ijk} s^2_{xijkl}}{2} \right] \right\} \tag{A4}$$

and where

$$s^2_{\hat{E}_{ij}} = \frac{\sum_{j=1}^{d_i} \left(\hat{E}_{ij} - \hat{\overline{E}}_i\right)^2}{\left(d_i - 1\right)},$$

$$\hat{\overline{E}}_i = \frac{\sum_{j=1}^{d_i} \hat{E}_{ij}}{d_i},$$

and further

$$s^2_{x_{ijkl}} = \frac{\sum_{l=1}^{2} \left(x_{ijkl} - \overline{x}_{ijk}\right)^2}{(2 - 1)},$$

$$\bar{x}_{ijk} = \frac{\sum_{l=1}^{2} x_{ijkl}}{2}.$$

The estimator for total annual entrainment for the Moss Landing Power Plant new combined-cycle units $\left(E_T\right)$ can then be written as

$$\hat{E}_T = \hat{E}_{CC}$$

where $\hat{E}_{CC}$ is the estimate of total annual entrainment at the combined-cycle units, based on repeated use of Equation (2). The variance for the estimator of total annual power plant entrainment can then be written as

$$V\hat{a}r\left(\hat{E}_T \middle| E_T\right) = V\hat{a}r\left(\hat{E}_{CC} \middle| E_{CC}\right). \qquad \text{(A5)}$$

Estimates of E_T will be used in *FH* and *AEL* calculations to estimate annual effects of entrainment on fish stocks.

Appendix B

Derivation of the Variance and Estimated Variance of $\hat{E}$

Variance of $\hat{E}$

The variance of $\hat{E}$ can be derived by taking the variance in stages by first conditioning on the choice of d_i days, then taking expectation over all selections of d_i of D_i days within the temporal stratum.

$$\begin{aligned}
Var\left(\hat{E}\right) &= E_{d_i}\left[Var\left(\hat{E}\middle|d_i\right)\right] + Var_{d_i}\left[E\left(\hat{E}\middle|d_i\right)\right] \\
&= E_{d_i}\left[Var\left(\sum_{i=1}^{L}\left(\frac{V_{Ti}}{V_i}\right)\sum_{j=2}^{d_i}\frac{V_{ijk}}{2}\sum_{l=1}^{2}x_{ijkl}\right)\right] \\
&\quad + Var_{d_i}\left[E\left(\sum_{i=1}^{L}\left(\frac{V_{Ti}}{V_i}\right)\sum_{j=1}^{d_i}\left[\sum_{k=1}^{4}\frac{V_{ijk}}{2}\sum_{l=1}^{2}x_{ijkl}\right]\right)\right] \\
&= E_{d_i}\left[\sum_{i=1}^{L}\left(\frac{V_{Ti}}{V_i}\right)^2\sum_{j=1}^{d_i}\sum_{k=1}^{4}\frac{V_{ijk}^2\left(1-\frac{2}{N_{ijk}}\right)S_{x_{ijkl}}^2}{2}\right] + Var_{d_i}\left[\sum_{i=1}^{L}\left(\frac{V_{Ti}}{V_i}\right)\sum_{j=1}^{d_i}E_{ij}\right] \qquad \text{(B1)} \\
&= \sum_{i=1}^{L}\left(\frac{V_{Ti}}{V_i}\right)^2\frac{d_i}{D_i}\sum_{j=1}^{D_i}\sum_{k=1}^{4}\frac{V_{ijk}^2\left(1-\frac{2}{N_{ijk}}\right)S_{x_{ijkl}}^2}{2} + \sum_{i=1}^{L}\left[\left(\frac{V_{Ti}}{V_i}\right)^2\frac{d_i^2\left(1-\frac{d_i}{D_i}\right)S_{E_{ij}}^2}{d_i}\right] \\
&= \sum_{i=1}^{L}\left\{\left(\frac{V_{Ti}}{V_i}\right)^2\left[\frac{d_i^2\left(1-\frac{d_i}{D_i}\right)S_{E_{ij}}^2}{d_i} + \frac{d_i}{D_i}\sum_{j=1}^{D_i}\sum_{k=1}^{4}V_{ijk}^2\frac{\left(1-\frac{2}{N_{ij}}\right)S_{x_{ijkl}}^2}{2}\right]\right\}
\end{aligned}$$

where

$$S_{E_{ij}}^2 = \frac{\sum_{j=1}^{D_i}\left(E_{ij}-\overline{E}_i\right)^2}{\left(D_i-1\right)},$$

$$\overline{E}_i = \frac{\sum_{j=1}^{D_i} E_{ij}}{D_i},$$

and where

$$S_{x_{ijkl}}^2 = \frac{\sum_{l=1}^{N_{ij}}\left(x_{ijkl}-\overline{X}_{ijk}\right)^2}{\left(N_{ij}-1\right)},$$

$$X_{ijk} = \frac{\sum_{l=1}^{N_{ijkl}} x_{ijkl}}{N_{ijkl}},$$

and furthermore

$$E_{ij} = \sum_{k=1}^{4}\sum_{l=1}^{N_{ijkl}} x_{ijkl} = \text{total entrainment for the } j\text{th day } \left(j=1,\ldots,D\right) \text{ in the } i\text{th stratum } \left(i=1,\ldots,L\right).$$

The finite population correction [i.e., $\left(1-\frac{2}{N_{ijk}}\right)$] will be nearly one in all cases and can be ignored.

Estimated Variance of $\hat{E}$

The variance for $\hat{E}$ is

$$Var\left(\hat{E}\middle|E\right) = \sum_{i=1}^{L}\left\{\left(\frac{V_{Ti}}{V_i}\right)^2\left[d_i\left(1-\frac{d_i}{D_i}\right)S_{E_{ij}}^2 + \frac{d_i}{D_i}\sum_{j=1}^{D_i}\sum_{k=1}^{4}V_{ijk}^2\frac{\left(1-\frac{2}{N_{ijk}}\right)S_{x_{ijkl}}^2}{2}\right]\right\}. \tag{B2}$$

The term

$$\frac{d_i}{D_i}\sum_{j=1}^{D_i}\sum_{k=1}^{4}V_{ijk}^2\frac{\left(1-\frac{2}{N_{ijk}}\right)S_{x_{ijkl}}^2}{2}$$

in Equation (B2) can be unbiasedly estimated by the quantity

$$\sum_{j=1}^{d_i}\sum_{k=1}^{4}V_{ijk}^2\frac{\left(1-\frac{2}{N_{ijk}}\right)s_{x_{ijkl}}^2}{2} \tag{B3}$$

when

$$s^2_{x_{ijkl}} = \frac{\sum_{l=1}^{2}\left(x_{ijkl} - \bar{x}_{ijk}\right)^2}{(2-1)}.$$

However,

$$E\left(s^2_{\hat{E}_{ij}}\right) \neq S^2_{E_{ij}}.$$

Instead,

$$Var\left(\hat{E}_{ij}\right) = Var\left(\sum_{k=1}^{4}\frac{V_{ijk}}{2}\sum_{l=1}^{2}x_{ijkl}\right)$$

taking the variance in stages

$$\begin{aligned}
Var\left(\hat{E}_{ij}\right) &= E_{d_i}\left[Var\left(\hat{E}_{ij}\middle|d_i\right)\right] + Var_{d_i}\left[Var\left(\hat{E}_{ij}\middle|d_i\right)\right] \\
&= E_{d_i}\left[Var\left(\sum_{k=1}^{4}\frac{V_{ijk}}{2}\middle|\sum_{l=1}^{2}x_{ijkl}\middle|d_i\right)\right] + Var_{d_i}\left[Var\left(\sum_{k=1}^{4}\frac{V_{ijk}}{2}\middle|\sum_{l=1}^{2}x_{ijkl}\middle|d_i\right)\right] \\
&= E_{d_i}\left[\sum_{k=1}^{4}\frac{V_{ijk}^2\left(1-\frac{2}{N_{ijk}}\right)S^2_{x_{ijkl}}}{2}\right] + Var_{d_i}\left[E_{ij}\right] \\
&= \left[\frac{1}{D_i}\sum_{j=1}^{D_i}\sum_{k=1}^{4}\left[\frac{V_{ijk}^2\left(1-\frac{2}{N_{ijk}}\right)S^2_{x_{ijkl}}}{2}\right]\right] + S^2_{E_{ij}}.
\end{aligned}$$

Hence,

$$E\left[d_i\left(1-\frac{d_i}{D_i}\right)s^2_{\hat{E}_{ij}}\right] = d_i\left(1-\frac{d_i}{D_i}\right)S^2_{E_{ij}} + \frac{d_i}{D_i}\left(1-\frac{d_i}{D_i}\right)\sum_{j=1}^{D_i}\sum_{k=1}^{4}\frac{V_{ijk}^2\left(1-\frac{2}{N_{ij}}\right)S^2_{x_{ijk}}}{2} \qquad \text{(B4)}$$

which has a positive bias of

$$\frac{d_i}{D_i}\left(1-\frac{d_i}{D_i}\right)\sum_{j=1}^{D}\sum_{k=1}^{4}\frac{V_{ijk}^2\left(1-\frac{2}{N_{ijk}}\right)S^2_{x_{ijk}}}{2} \qquad \text{(B5)}$$

In turn, the bias (B5) can be estimated by the quantity

$$\left(1-\frac{d_i}{D_i}\right)\sum_{j=1}^{d_i}\sum_{k=1}^{4}\frac{V_{ijk}^2\left(1-\frac{2}{N_{ijk}}\right)s_{x_{ijk}}^2}{2}. \tag{B6}$$

An estimator of $Var\left(\hat{E}\middle|E\right)$ can then be expressed by taking into account Equations (B3-B6) as

$$\begin{aligned}
V\hat{a}r\left(\hat{E}\middle|E\right) &= \sum_{i=1}^{L}\left\{\left(\frac{V_{Ti}}{V_i}\right)^2\left[d_i\left(1-\frac{d_i}{D_i}\right)s_{E_{ij}}^2-\left(1-\frac{d_i}{D_i}\right)\sum_{j=1}^{d_i}\sum_{k=1}^{4}\frac{V_{ijk}^2\left(1-\frac{2}{N_{ijk}}\right)s_{x_{ijk}}^2}{2}\right]\right. \\
&\qquad \left.+\sum_{j=1}^{d_i}\sum_{k=1}^{4}\frac{V_{ijk}^2\left(1-\frac{2}{N_{ijk}}\right)s_{x_{ijk}}^2}{2}\right\} \\
&= \sum_{i=1}^{L}\left\{\left(\frac{V_{Ti}}{V_i}\right)^2\left[d_i\left(1-\frac{d_i}{D_i}\right)s_{E_{ij}}^2+\frac{d_i}{D_i}\sum_{j=1}^{d_i}\sum_{k=1}^{4}\frac{V_{ijk}^2\left(1-\frac{2}{N_{ijk}}\right)s_{x_{ijk}}^2}{2}\right]\right\}.
\end{aligned}$$

Appendix C

Estimating Proportional Entrainment and the *ETM* Calculations

The empirical transport model (*ETM*) attempts to estimate the total annual mortality probability for larvae from power plant entrainment. The annual estimate is based on periodic daily probabilities of entrainment mortality. The calculations will assume all larvae entrained die.

The daily probability of entrainment can be defined as

$$\begin{aligned} P_{M_{ij}} &= \frac{\text{abundance of entrained larvae}_{\text{ij}}}{\text{abundance of larvae in source population}_{\text{ij}}} \\ &= \text{probability of entrainment on the } j\text{th day } \left(j = 1, \ldots, d_i\right) \\ &\quad \text{of the } i\text{th temporal stratum } (i = 1, \ldots, L). \end{aligned}$$

In turn, the daily probability can be estimated and expressed as

$$P_{M_{ij}} = \frac{\hat{E}_{ij}^{T}}{\hat{R}_{ij}} \tag{C1}$$

where

$\hat{E}_{ij}^{T}$ = estimated abundance of larvae entrained on the jth day $\left(j = 1, \ldots, d_i\right)$ of the ith stratum $(i = 1, \ldots, L)$;

$\hat{R}_{ij}$ = estimated abundance of larvae at risk of entrainment from the source populations on the jth day $\left(j = 1, \ldots, d_i\right)$ of the ith stratum $(i = 1, \ldots, L)$.

Estimating Daily Entrainment

The estimate of total daily entrainment $\left(E_{ij}^{T}\right)$ at the combined-cycle units can be written as

$$\hat{E}_{ij}^{T} = \hat{E}_{ij}^{CC} \tag{C2}$$

where E_{ij}^{CC} is the estimate of daily entrainment for the combined-cycle units intake.

At any one intake site, the estimate of entrainment can be expressed as

$$\hat{E}_{ij} = \sum_{k=1}^{4} \frac{V_{jk}}{2} \sum_{l=1}^{2} x_{ijkl} \tag{C3}$$

with associated variance

$$Var\left(\hat{E}_{ij} \middle| E_{ij}\right) = \sum_{k=1}^{4} \frac{V_{jk}^{2}\left(1 - \frac{2}{N_{ijk}}\right) S_{x_{ijk;}}^{2}}{2} \tag{C4}$$

which can be estimated by

$$V\hat{a}r\left(\hat{E}_{ij} \middle| E_{ij}\right) = \sum_{k=1}^{4} V_{jk}^{2} \frac{\left(1 - \frac{2}{N_{ijk}}\right) s_{x_{ijkl}}^{2}}{2}. \tag{C5}$$

Typically, the finite population correction [i.e., $\left(1 - \frac{2}{N_{ijk}}\right)$] can be ignored for N_{ijk} is exceedingly large.

Estimating Daily Numbers of Larvae at Risk

With the well-defined and agreed-upon sources of Monterey Bay (MB), Moss Landing Harbor (MLH), and Elkhorn Slough (ES), the daily abundance of larvae at risk can be estimated by

$$\hat{R}_{ij} = V_{MB} \cdot \hat{\overline{D}}_{MB_{ij}} + V_{MLH} \cdot \hat{\overline{D}}_{MLH_{ij}} + V_{ES} \cdot \hat{\overline{D}}_{ES_{ij}} \tag{C6}$$

where V denotes volume at Monterey Bay (MB), Moss Landing Harbor (MLH), or Elkhorn Slough (ES), and $\hat{\overline{D}}$ denotes an estimate of average density. The variance of Expression (C6) can be written as

$$\begin{aligned} Var\left(\hat{R}_{ij} \middle| R_{ij}\right) = {} & V_{MB}^{2} \cdot Var\left(\hat{\overline{D}}_{MB_{ij}} \middle| \hat{\overline{D}}_{MB_{ij}}\right) + V_{MLH}^{2} \cdot Var\left(\hat{\overline{D}}_{MLH_{ij}} \middle| \overline{D}_{MLH_{ij}}\right) \\ & + V_{ES}^{2} \cdot Var\left(\hat{\overline{D}}_{ES_{ij}} \middle| \overline{D}_{ES_{ij}}\right). \end{aligned} \tag{C7}$$

The individual variances within Formula (C7) describe temporal-spatial variance in density within a source population during the day of sampling. Within Moss Landing Harbor and Monterey Bay, four sampling stations have now been proposed (TWG meeting September 15, 1999). With Elkhorn Slough, 2 fixed-location sites were selected for sampling (i.e., The Dairies and Kirby Park). Ideally, tow samples would be collected probablistically through time and space during a sampling day at a potential source population.

Variance for Daily Estimate of $\hat{P}M_{ij}$

The variance for the daily estimate of $\hat{P}M_{ij}$ can be expressed as

$$Var\left(\hat{P}M_{ij}\middle|PM_{ij}\right) \doteq Var\left(\frac{\hat{E}_{ij}}{\hat{R}_{ij}}\middle|E_{ij}, R_{ij}\right)$$

which by the Delta method can be approximated by

$$Var\left(\hat{P}M_{ij}\middle|PM_{ij}\right) \doteq \left(\frac{E_{ij}}{R_{ij}}\right)^2\left[\frac{Var\left(\hat{E}_{ij}\middle|E_{ij}\right)}{E_{ij}^2}+\frac{Var\left(\hat{R}_{ij}\middle|R_{ij}\right)}{R_{ij}^2}\right] \tag{C8}$$

and can be estimated by

$$V\hat{a}r\left(\hat{P}M_{ij}\middle|PM_{ij}\right) = \left(\hat{P}M_{ij}\right)^2\left[\hat{C}V\left(\hat{E}_{ij}\middle|E_{ij}\right)^2 + \hat{C}V\left(\hat{R}_{ij}\middle|R_{ij}\right)^2\right]$$

where

$$\hat{C}V\left(\hat{\theta}\middle|\theta\right) = \frac{V\hat{a}r\left(\hat{\theta}\middle|\theta\right)}{\hat{\theta}^2}.$$

ETM Calculations

By combining Equations (C1), (C2), and (C6), the estimate of daily entrainment mortality can be written as

$$\begin{aligned}\hat{P}_{M,ij} &= \frac{\hat{E}_{ij}^{CC}}{\left(V_{MB}\cdot\hat{\hat{D}}_{MB_{ij}} + V_{MLH}\cdot\hat{\hat{D}}_{MLH_{ij}} + V_{ES}\cdot\hat{\hat{D}}_{ES_{ij}}\right)} \\ &= \frac{\hat{E}_{ij}^{T}}{\hat{R}_{ij}}.\end{aligned} \tag{C9}$$

If the species has a single spawning period per year, then the estimate of total annual mortality can be expressed by

$$\hat{P}M = 1 - \prod_{i=1}^{L}\prod_{j=1}^{d_i}\left(1-\hat{P}M_{ij}\right)^{D'_{ij}} \tag{C10}$$

where

D'_{ij} = number of days represented by the jth sample $\left(j=1,\ldots,d_i\right)$ in the ith temporal stratum $\left(i=1,\ldots,L\right)$.

Alternatively, if the species has multiple overlapping spawnings, then an estimate of total annual entrainment can be based on the formula

$$\hat{P}M = 1-\sum_{i=1}^{L}\sum_{j=1}^{d_i}\hat{f}_{ij}\left(1-\hat{P}M_{ij}\right)^{D'_{ij}} \tag{C11}$$

where

$\hat{f}_{ij}$ = estimated annual fraction of total larvae hatched during the survey period represented by the *j*th sample in the *i*th temporal stratum.

Formula (C11) is based on the total probability law where

$$P(A)=\sum_{i=1}^{N}P\left(A|B_i\right)\cdot P\left(B_i\right).$$

In the above example, the event A is larval survival and event B is hatching with $P\left(B\right)$ estimated by $\hat{f}_{ij}$.

Appendix D
Delta Method for Calculating Variance

Variance for $P\hat{E}_i$

Using the delta method (Seber, 1984), variance of $P\hat{E}_i$ can be effectively approximated by

$$
\begin{aligned}
Var(P\hat{E}_i) &= Var\left(\frac{\hat{N}}{(1+\hat{f})\hat{A}_i}\right) \\
&= Var(\hat{N}_i)\left(\frac{1}{(1+f_i)A_i}\right)^2 + Var(\hat{f}_i)\left(\frac{-N_i}{A_i(1+f_i)^2}\right)^2 \\
&\quad + Var(A_i)\left(\frac{-N_i}{(1+f)A_i^2}\right)^2 \\
&= \left(\frac{-N_i}{(1+f_i)A_i}\right)^2\left[\frac{Var(\hat{N}_i)}{N_i^2} + \frac{Var(\hat{f}_i)}{(1+f_i)^2} + \frac{Var(\hat{A}_i)}{A_i^2}\right] \\
&= PE_i^2[CV(\hat{N}_i)^2 + CV(1+\hat{f})^2 + CV(\hat{A}_i)^2] \quad .
\end{aligned}
$$

Variance for S_A

can be estimated from

$$\hat{S}_A = \frac{2}{\hat{F}\cdot\hat{R}\cdot\hat{S}_E\cdot\hat{S}_L}$$

where:

$\hat{\bar{F}} =$ average egg mass per female per year;

$\hat{R} =$ reproduction longevity, average number of years of reproduction for a female;

$\hat{S}_E =$ egg survival rate;

$\hat{S}_L =$ survival of larvae from hatching to time of entrainment.

The variance of $\hat{S}_A$ based on the delta method is then estimated by the approximate formula

$$V\hat{a}r(\hat{S}_A) = S_A^2 \left[\frac{V\hat{a}r(\hat{\hat{F}})}{\hat{F}^2} + \frac{V\hat{a}r(\hat{R})}{\hat{R}^2} + \frac{V\hat{a}r(\hat{S}_E)}{\hat{S}_E^2} + \frac{V\hat{a}r(\hat{S}_L)}{\hat{S}_L^2} \right] .$$

For the example of monkeyface eel, the variance of $\hat{S}_A$ is estimated as

$$\begin{aligned} Var(\hat{S}_A) &= (0.0001388)^2 \left[\frac{(4{,}667)^2}{(32{,}000)^2} + \frac{(2.08)^2}{(11.75)^2} + \frac{(0.0373)^2}{(0.4240)^2} + \frac{(0.0314)^2}{(0.0904)^2} \right] \\ &= 0.0000000035 \end{aligned}$$

or

$$\hat{S}E(\hat{S}_A) = 0.00005905 \quad .$$

Variance for $A\hat{E}L$

The estimator of adult equivalent loss is

$$A\hat{E}L = \hat{E}_T \cdot \hat{S}_A$$

with exact variance

$$Var(A\hat{E}L) = Var(\hat{E}_T) \cdot S_A^2 + Var(\hat{S}_A)^2 \cdot E_T^2 + Var(\hat{E}_T)^2 \cdot Var(\hat{S}_A) \quad .$$

Using the variance formula in conjunction with the monkeyface eel data results in an estimated variance of

$$\begin{aligned} V\hat{a}r(A\hat{E}L) &= (197{,}677{,}101)^2 (0.0001388)^2 + (0.00005905)^2 (160{,}544{,}555)^2 + (192{,}677{,}101)^2 (0.00005905) \\ &= 934{,}541{,}905.8 \end{aligned}$$

or

$$\hat{S}E(A\hat{E}L) = 30{,}570.3 \quad .$$

Variance for $\hat{F}H$

The estimator of hindcast fecundity lost is

$$\hat{F}H = \frac{\hat{E}_T}{\hat{S}_E \cdot \hat{S}_L \cdot \hat{\hat{F}}_T}$$

where

$\hat{E}_T =$ estimated total entrainment of larvae;

$\hat{S}_E =$ survival probability for eggs;

$\hat{S}_L =$ survival of larvae from hatching to time of entrainment;

$\hat{\bar{F}}_T =$ estimated average total lifetime fecundity $= \hat{F} \cdot \hat{R}$.

Using the Delta method, an approximate variance estimator is

$$V\hat{a}r(\hat{F}H) = FH^2 \left[\frac{V\hat{a}r(\hat{E}_T)}{\hat{E}_T^{\;2}} + \frac{V\hat{a}r(\hat{S}_E)}{\hat{S}_E^{\;2}} + \frac{V\hat{a}r(\hat{S}_L)}{\hat{S}_L^2} + \frac{V\hat{a}r(\hat{F})}{\hat{F}^2} + \frac{V\hat{a}r(\hat{R})}{\hat{R}^2} \right] .$$

For the example of monkeyface eel, the variance of $\hat{F}H$ is calculated to be

$$\begin{aligned} V\hat{a}r(\hat{F}H) &= (11{,}140)^2 \left[\frac{(192{,}677{,}101)^2}{(160{,}544{,}555)^2} + \frac{(0.0373)^2}{(0.4240)^2} + \frac{(0.0314)^2}{(0.0904)^2} + \frac{(4{,}667)^2}{(32{,}000)^2} + \frac{(2.08)^2}{(11.75)^2} \right] \\ &= 201{,}208{,}630 \end{aligned}$$

or

$$\hat{S}E(\hat{F}H) = 14{,}185$$