4.0 IMPINGEMENT STUDY

4.1 Introduction

The two primary ways cooling water withdrawal can affect aquatic organisms are through impingement and entrainment. The power plant's cooling water intake system (CWIS) contains two sets of vertical traveling screens that exclude debris and organisms from the system. Impingement occurs when an organism larger than the traveling screen mesh size is trapped against the screens. These impinged organisms are assumed to undergo 100 percent mortality for the purposes of this study.

The purpose of this study, conducted from September 9, 1999 through September 8, 2000, was to characterize the juvenile and adult fishes and selected macroinvertebrates (shrimps, crabs, sea urchins, squid, and octopus) impinged by the power plant's CWIS. The sampling program was designed to provide estimates of the abundance, taxonomic composition, diel periodicity, and seasonality of organisms impinged at the MBPP. In particular, this study focused on the rates (i.e., number or biomass of organisms per m^3 water flowing per time into the plant) at which various species of fishes and macroinvertebrates are impinged. The impingement rate is subject to tidal and seasonal influences that vary on several temporal scales (e.g., hourly, daily, and monthly) while the rate of cooling water flow varies with power plant operations and can change at any time. Data collected from weekly surveys is presented in Appendix H.

The data collected during this study are used to assess the potential impacts of a proposed modernization of the plant (See Section 5.0 – Impact Assessment). The proposed modernization will result in a reduction of the impingement effects measured in this study through a combination of reduced approach velocities at the traveling screens and a reduction in the total cooling water volume withdrawal. A review of previous studies, trends, and conclusions regarding impingement at the existing CWIS at the MBPP provided some context for the 1999 – 2000 impingement study program. Studies of the Morro Bay fish assemblages independent of the MBPP were also reviewed to provide information regarding the marine environment in and around Morro Bay. The results from the 1999 – 2000 study are presented in this section.

4.2 Background

4.2.1 Current Cooling Water System Design Features

Two separate shoreline intake structures, one for Units 1 and 2 and one for Units 3 and 4, withdraw cooling water from the northeastern shore of Morro Bay. The shoreline intake structures for the MBPP enclose the bar racks, vertical traveling screens, and chlorination systems. Circulating water pumps serving the individual units are located about 10 m (30 ft) behind the screen structure. Each unit is equipped with two circulating water pumps that discharge into separate pressure conduits, each supplying one half of a unit's steam condenser. Seawater entering the intake structures first passes through the bar racks that are designed to prevent the entry of large objects into the cooling water system. These bar racks are spaced 10.2 cm (4 in.) on center and are located about 6 m (20 ft) in front of the vertical traveling screens.

From the bar racks, water flows into the pump forebays, where the vertical traveling screens are housed. The screens, fabricated from 0.95 cm (3/8 in.) mesh, retain objects small enough to pass through the bar racks but larger than 0.95 cm. There are four vertical traveling screens for Units 1 and 2 and six vertical traveling screens for Units 3 and 4. Each of the traveling screens is approximately 3 m (10 ft) wide and extends from the upper decking of the intake structure to its base 5 m (16 ft) below mean lower low water (MLLW). Debris, fishes, and invertebrates retained by the traveling screens are removed during periodic screen rotation and washing. Screen washes can be initiated by timed cycles (approximately every four hours), by manual operation (typically a continuous wash which may be necessary during periods of heavy algae and eelgrass accumulation), or by automatic activation caused by the differential water pressure across the screens exceeding a predetermined maximum.

During screen washing, high-pressure nozzles (90 – 95 psi) wash debris and impinged organisms from the traveling screens. This material is washed from the traveling screens into sloping sluiceways that empty into two refuse sumps (one per unit group). Impinged material from all the units is returned to Estero Bay by a large diameter pump that empties into the discharge conduit of Units 1 and 2.

4.2.2 Previous Impingement Study

In 1983, Ecological Analysts, Inc. completed the *Morro Bay Power Plant Cooling Water Intake Structures 316(b) Demonstration* (PG&E 1983). The impingement chapter of this study was based, in part, on the studies conducted by Behrens and Sommerville (1982). Their results indicated that the most abundant fishes impinged were shiner perch *Cymatogaster aggregata* (76 percent of which were newborns), northern anchovy *Engraulis* mordax (mainly age zero year class), plainfin midshipman *Porichthys notatus*, (mainly age class one to two years) topsmelt *Atherinops affinis* (mainly age class three years) and bocaccio *Sebastes paucispinis* (mainly young-of-the-year [YOY]). The most abundant macroinvertebrates were rock crabs *Cancer* spp., a variety of shrimp *Crangon* spp., and market squid *Loligo opalescens*. Regulatory decisions based on the results of this study determined that the intake structures at the MBPP represented the best technology available (BTA) to minimize adverse impacts and the National Pollutant Discharge Elimination System (NPDES) permit was renewed.

4.2.3 Other Related Studies

Several studies on juvenile and adult fishes have been conducted in the vicinity of the MBPP. Fierstine et al. (1973) documented the spatial distribution and seasonal changes in the adult fish assemblage in the Morro Bay estuary. A synoptic study of the MBPP thermal discharge was conducted from 1971 – 1972 (PG&E 1973) to characterize the adult fish community in Estero Bay. Horn (1980) conducted quarterly bag seine sampling between 1974 and 1976 to characterize the temporal variation (diel and seasonal) and diversity of the shallow water adult fish assemblage in Morro Bay. The California Department of Fish and Game (CDFG) presently conducts monthly or semi-monthly otter trawl surveys in the Morro Bay estuary to monitor the abundance of commercially and recreationally important fish species; these surveys began in April 1992. A listing of all fish taxa collected during these studies is presented in Appendix B.

The three studies of adult and juvenile fishes in Morro Bay mentioned above demonstrate that their composition and abundance over a decade of sampling has remained relatively constant. Horn (1980) collected 11,627 fishes comprised of 21 species captured in 36 seine hauls. Three species (topsmelt, shiner perch, and Pacific staghorn sculpin *Leptocottus armatus*) numerically dominated the samples and comprised 82 percent of the fishes collected. These three species were also common in Fierstine et al.'s (1973) Morro Bay studies. Topsmelt and shiner perch were also two of the top five abundant species collected in Behrens and Sommerville's (1982) MBPP impingement studies. Other species common to these studies were plainfin midshipman (missing from Horn 1980) and northern anchovy.

Some of the fishes that occur in Morro Bay are residents while others are seasonal visitors. Fierstine et al. (1973) reported that 12 species they considered residents occurred in at least six or more of their survey months. Another 26 species that they designated seasonal or occasional visitors were collected in a single month. Transient fishes may be found using the estuary as nursery grounds (e.g., plainfin midshipman or sharks and rays), feeding grounds (Pacific sardine

Sardinops sagax), or as a migratory corridor (e.g., steelhead *Oncorhynchus mykiss* during the spring and summer).

Moyle and Cech (1988) further separate estuary residents into three types of fishes. These are true estuarine fishes like the Delta smelt *Hypomesus transpacificus* (found only in the Sacramento-San Joaquin Delta), nondependent marine fishes commonly found in estuaries but do not depend on estuaries to complete their life cycle (e.g., Pacific staghorn sculpin), and dependent marine fishes that spend at least one stage of their life cycle (e.g., spawning, nurseries, adult feeding grounds) within the estuary (e.g., Pacific herring *Clupea pallasii*). The majority of the resident fishes referred to in previous studies of Morro Bay can be classified into the latter two types of residents (i.e., nondependent or dependent marine fishes). Very few species can be considered true estuarine fishes (Moyle and Cech 1988), and these estuarine fishes usually comprise only a few species in any given estuary.

4.2.4 Additional Information

There is an active fishing industry in the Port of Morro Bay. Both commercial and sportfishing vessels embark from the port and fish in local waters; landing their catches in Morro Bay. Private recreational fishers also embark from the port or fish from the piers and nearby shoreline. Fishing, fishing-related activities, and tourism contribute to the city of Morro Bay's annual economy.

The California Department of Fish and Game (CDFG) and Pacific States Marine Fisheries Commission (PSMFC) maintain data on commercial, sport, and recreational catches for California that are accessible to the public. We used these data in Section 5.0 to place MBPP's impingement losses into context with the local fishery catches and landings. In most cases, this meant converting estimated biomass impinged into dollar values using market prices reported by CDFG and PSMFC. The CDFG and PSMFC data used to calculate market prices are presented in Appendix I.

4.3 Study Purpose

Fishes and selected macroinvertebrates impinged at the MBPP intakes were sampled to assess the potential population-level impacts of impingement by the existing CWIS. Corollary data on flow rates and cooling water volumes were recorded for the samples collected. This assessment will specifically address the following questions:

- What are the composition and abundance of juvenile and adult fishes and selected macroinvertebrates impinged by the MBPP?

- What are the abundance and distribution of source water species of impingeable fishes and selected macroinvertebrates in Morro Bay?

- What are the potential impacts of MBPP's cooling water system on local populations of fishes and selected macroinvertebrates?

4.4 Methods

4.4.1 Sample Collection

Organisms impinged in MBPP's CWIS were sampled during a 24-hour period one day per week from September 9, 1999 through September 8, 2000. Each sampling period was divided into approximately six 4-hour cycles. A sample consisted of all organisms impinged and washed from the traveling screens during the 24-hour period; including non-scheduled wash downs that may have occurred during each cycle. In addition to identifying and enumerating the fishes and macroinvertebrates impinged, operating status of the circulating water pumps and environmental data (water temperatures and tidal height) were recorded for each cycle. Circulating water pump logs (hourly) were supplied by Duke Energy for all weekly survey periods.

Samples were collected in ¼ in. stainless steel mesh baskets placed in the sluiceways above the sump pumps. The impinged material was washed from the traveling screens and flushed down the sluiceways into the collection baskets; two baskets for Units 1 and 2 and two baskets for Units 3 and 4. Both baskets per unit group were combined, but Units 1 and 2 were processed separately from the material collected at Units 3 and 4. The impinged material from unscheduled traveling screen washes (e.g., differential pressure wash) was also incorporated into the sub-samples for that unit group during collection cycle.

All fishes and selected macroinvertebrates in each sample were identified and enumerated. Criteria were established *a priori* for the types of data to be collected from each taxonomic category (Table 4-1). Weights and lengths of bony fishes (teleosts) and sharks and rays (elasmobranchs) were recorded; standard length (SL) for the bony fishes and total length (TL) for the sharks and rays. Any fish fragments or mutilated fishes collected were identified, if possible, but no length or weight data were recorded. These data records were included in estimates of impingement losses in a manner similar to the method used to assign individual weights to batch-weighed organisms (i.e., an average individual weight from the concurrent survey data was applied to the fragments or to the individuals in the enumerated batches). Carapace width, carapace length, dorsal mantle length, and test diameter were measured for crabs, shrimps, cephalopod mollusks, and sea urchins, respectively. All lengths were recorded to the nearest 0.1 mm and all weights to the nearest 0.1 g. The condition (alive, dead, or mutilated) of the organism was also recorded as was the volume of the impinged debris. All data were recorded on data sheets, verified, and subsequently entered into a computer database (Microsoft Access™).

A quality control (QC) program was implemented to ensure the correct identification, enumeration, and collection of length and weight measurements for the organisms impinged. Impingement cycles were randomly chosen for onsite QC re-sort to verify that all the organisms were removed from the impinged material. A QC program was also in place to assure the accuracy of data recorded on the datasheets.

Table 4-1. Sample processing and data collection criteria for the MBPP impingement study.

Count	Length	Weight	Condition of Specimen	Sex	Organism Type/Comments
X	X	X	X	X	Elasmobranchs (sharks, skates, rays) Total length measured.
X	X	X	X	–	Teleosts (bony fishes) Standard length measured.
X	X	X	X	X	Decapod crabs Carapace width measured.
X	X	X	X	X	Cephalopod molluscs (octopi and squid) Mantle length measured.
X	X	X	X	–	Sea urchins Test diameter measured.

'X' = data collected for this organism
– = data *not* collected for this organism

Occasionally, high levels of debris or a great number of invertebrates (e.g., jellyfish) were present at the traveling screens necessitating continuous screen washing. At these times, sample collection was suspended since it was unsafe to install and remove the collection baskets. Typically, these conditions also resulted in the termination of that weekly survey.

4.4.2 Selection of Target Organisms

The impinged fish and invertebrate taxa selected for analysis in this study were chosen on the basis of both numeric abundance and biomass. Abundance data were analyzed to determine the species that comprised the top 90 percent of impingement for each class of organism. These were considered to be both representative of impingement losses and likely to contain species whose populations were potentially affected by those losses. These species lists were further refined to incorporate those taxa that were both numerically abundant as well as impinged in high biomass. This process ensures that the organisms examined in this report are those with the greatest potential to experience population-level effects due to impingement losses at the MBPP.

4.4.3 Data Analyses

Impingement estimates for species and taxonomic groups were obtained by first calculating cooling water flow during each screen wash cycle sampled during the 24-hour survey. The total time for each screen wash cycle was multiplied by the flow rate for either Units 1 and 2 (697 m^3pm [184,000 gpm] maximum) or Units 3 and 4 (1,060 m^3pm [280,000 gpm] maximum) as appropriate. Flow rate was then adjusted for each unit group based on the number of pumps operating during the screen wash cycle. For example, if only 2 of the 4 pumps were operating, the total flow rate would be reduced by half. The flows from the screen wash cycles were then added to obtain the total flow for the entire 24-hour collection period. This flow was used in calculating an impingement rate for each unit group (Units 1 and 2 or Units 3 and 4) based on the total number of organisms for a species or taxonomic group collected from an impingement survey.

Subsampling was used to contend with any large influx of a single taxon. When a large number of individuals from a single taxon were collected during a cycle, the first 50 were measured and weighed while the remainder were counted and batch-weighed. For these taxa, weights and counts for the measured individuals were totaled and then an average weight per individual was calculated. This unit weight per individual was multiplied by the total count (including the individuals that were not weighed) to obtain an estimate of the total weight for each cycle. The counts and weights were then totaled for each 24-hour collection period.

The calculated impingement rate for each taxon over the 24-hour collection period was used to obtain an estimate of the impingement rate for the entire weekly survey period. The days between impingement collections were assigned to each weekly survey period by using the collection day as the median day within the period and assigning the days on either side of that collection date to create a weekly survey period. In most cases, the weekly survey periods were 7 days, but when weekly surveys were not conducted, the periods were longer. The flow rates for the days within each survey period were obtained from the system operator log records at the power plant. The total calculated flow for the weekly survey period was multiplied by the taxon-specific impingement rate calculated for the survey to obtain estimates of impingement counts and weights for the survey period. Occasionally, the only individuals collected for a taxon during an impingement survey were mutilated and therefore no biomass estimates were available for those surveys. Finally, the total biomass and abundance estimates for each survey period were summed to obtain annual estimates for each taxon.

4.5 Results

4.5.1 Sampling

Data presented in this report are from weekly 24-hour impingement collections beginning September 9, 1999 and continuing through September 8, 2000. In total, 106 fish taxa and 53 of the macroinvertebrate taxa selected for enumeration were recorded from these collections (Tables 4-2 and 4-3, respectively). The 106 fish taxa included nearly 11,000 individuals, which had a combined weight of 167 kg (369 lb). The values for each approximately week-long survey were expanded by flow volumes to estimate impingement totals of approximately 74,000 fishes with a combined weight of 1.1 metric tons (MT) (1.3 short tons [T]) for the year-long study period. Although 257 macroinvertebrate taxa were recorded during the study, only crabs, shrimps, cephalopods, and sea urchins were enumerated and measured. The counted taxa included over 7,600 individuals from the weekly 24-hour surveys, which had a combined weight of 52 kg (115 lb). These values were expanded by flow volumes over each approximately week-long survey period to yield estimated impingement totals for the year of approximately 53,000 selected macroinvertebrates weighing 360 kg (793 lb).

Table 4-2. Total counts and weights of fishes collected during impingement surveys from September 9, 1999 through September 8, 2000 at the MBPP Units 1–4 intakes combined. Total impingement was estimated by expanding the count and weight for each survey with its cooling water volume over the study period.

Taxon	Common Name	Actual Impingement Sample Totals	Actual Impingement Sample Totals		Estimated Total Impingement	Estimated Total Impingement	
		(#)	(g)	(lb)	(#)	(g)	(lb)
Engraulis mordax	northern anchovy	8,063	64,868.3	143.01	54,170	434,317.0	957.50
Atherinops affinis	topsmelt	693	23,343.6	51.46	4,124	137,504.3	303.14
Porichthys notatus	plainfin midshipman	543	21,123.9	46.57	3,944	152,565.1	336.35
Citharichthys stigmaeus	speckled sanddab	341	1,096.8	2.42	2,345	7,627.0	16.81
Symphurus atricauda	California tonguefish	207	1,124.2	2.48	1,374	7,504.9	16.55
Leptocottus armatus	Pacific staghorn sculpin	190	2,140.1	4.72	1,512	16,929.8	37.32
Parophrys vetulus	English sole	144	404.4	0.89	1,032	2,873.8	6.34
**Scorpaenidae (total)	**rockfishes (total)	**60	**1,434.1	**3.16	**448	**9,479.1	**20.90
Sardinops sagax	Pacific sardine	57	3,212.2	7.08	421	24,372.4	53.73
Cymatogaster aggregata	shiner surfperch	45	726.7	1.60	364	5,769.1	12.72
Scorpaenichthys marmoratus	cabezon	45	3,348.5	7.38	349	23,698.5	52.25
Platyrhinoidis triseriata	thornback	44	28,987.9	63.91	316	213,240.7	470.11
Citharichthys sordidus	Pacific sanddab	43	196.9	0.43	274	1,263.4	2.79
Syngnathus leptorhynchus	bay pipefish	41	173.5	0.38	290	1,166.6	2.57
Syngnathus spp.	pipefishes	35	89.2	0.20	272	692.1	1.53
Ophiodon elongatus	lingcod	32	212.0	0.47	224	1,470.2	3.24
Ophidion scrippsae	basketweave cusk-eel	31	575.2	1.27	187	3,583.7	7.90
Chilara taylori	spotted cusk-eel	26	960.0	2.12	194	7,253.7	15.99
Myliobatis californica	bat ray	25	6,816.8	15.03	173	47,004.7	103.63
Artedius spp.	sculpins	14	120.0	0.26	98	794.8	1.75
Artedius lateralis	smoothhead sculpin	12	91.7	0.20	92	776.2	1.71
Embiotoca lateralis	striped surfperch	12	792.8	1.75	98	4,839.8	10.67
Hyperprosopon argenteum	walleye surfperch	11	94.1	0.21	100	653.4	1.44
Icichthys lockingtoni	medusa fish	11	235.0	0.52	130	2,932.8	6.47
Syngnathus californiensis	kelp pipefish	11	44.0	0.10	72	293.2	0.65
Amphistichus argenteus	barred surfperch	10	54.7	0.12	78	444.5	0.98
Aulorhynchus flavidus	tubesnout	10	23.1	0.05	85	209.7	0.46
Phanerodon furcatus	white surfperch	10	42.6	0.09	79	334.6	0.74
Sebastes spp.	rockfishes	10	399.4	0.88	76	2,840.5	6.26
Embiotoca jacksoni	black surfperch	8	986.7	2.18	59	6,578.8	14.50
Sebastes rastrelliger	grass rockfish	8	423.8	0.93	51	2,479.1	5.47
Sebastes melanops	black rockfish	8	29.5	0.07	70	218.8	0.48
Microstomus pacificus	Dover sole	7	20.6	0.05	45	128.3	0.28
Sebastes atrovirens	kelp rockfish	7	55.1	0.12	51	359.0	0.79
Cottidae unid.	sculpins	6	92.9	0.20	52	890.6	1.96
Hexagrammos decagrammus	kelp greenling	6	218.9	0.48	38	1,404.9	3.10
Sebastes atrovirens (juv.)	kelp rockfish	6	176.2	0.39	39	1,155.8	2.55
Sebastes chrysomelas	black and yellow rockfish	5	88.6	0.20	35	607.4	1.34
Apodichthys flavidus	penpoint gunnel	5	130.3	0.29	40	1,058.3	2.33
Citharichthys spp.	sanddabs	5	1.8	<0.01	36	13.6	0.03
Gobiesox maeandricus	northern clingfish	5	11.8	0.03	34	77.0	0.17
Torpedo californica	Pacific electric ray	5	752.4	1.66	35	5,413.1	11.93
Damalichthys vacca	pile surfperch	4	1,147.6	2.53	32	7,328.2	16.16
Embiotocidae	surfperches	4	14.6	0.03	29	108.8	0.24
Hypsurus caryi	rainbow surfperch	4	27.9	0.06	38	246.8	0.54
Oligocottus snyderi	fluffy sculpin	4	16.8	0.04	29	122.0	0.27
Peprilus simillimus	Pacific butterfish	4	3.1	0.01	38	32.1	0.07
Stichaeidae unid.	pricklebacks	4	20.2	0.04	27	132.0	0.29
Sebastes carnatus	gopher rockfish	3	43.3	0.10	24	320.2	0.71
Atherinidae unid.	silversides	3	0.8	<0.01	26	8.7	0.02
Atherinopsis californiensis	jacksmelt	3	5.2	0.01	20	33.6	0.07
Genyonemus lineatus	white croaker	3	4.9	0.01	22	35.0	0.08
Gibbonsia metzi	striped kelpfish	3	63.6	0.14	19	404.6	0.89
Osmeridae unid.	smelts	3	7.0	0.02	19	42.4	0.09
Agonidae unid.	poachers	2	51.9	0.11	12	333.1	0.73
Gibbonsia montereyensis	crevice kelpfish	2	19.7	0.04	14	129.3	0.29
Gibbonsia spp.	clinid kelpfishes	2	13.9	0.03	16	111.0	0.24
Hypsoblennius gilberti	rockpool blenny	2	51.7	0.11	15	400.1	0.88
Odontopyxis trispinosa	pygmy poacher	2	2.9	0.01	13	19.6	0.04
Pholididae/Stichaeidae unid.	gunnel/prickleback	2	0.2	<0.01	13	1.3	<0.01
Pleuronichthys coenosus	c-o turbot	2	2.8	0.01	14	19.2	0.04
Pleuronichthys decurrens	curlfin turbot	2	63.6	0.14	14	376.3	0.83
Sebastes paucispinis	bocaccio	2	7.1	0.02	14	48.3	0.11
Sebastes serranoides	olive rockfish	2	2.3	0.01	19	22.9	0.05
Spirinchus starksi	night smelt	2	19.1	0.04	12	117.8	0.26

(*continued*)

Table 4-2 (continued). Total counts and weights of fishes collected during impingement surveys from September 9, 1999 through September 8, 2000 at the MBPP Units 1–4 intakes combined. Total impingement was estimated by expanding the count and weight for each survey with its cooling water volume over the study period.

Taxon	Common Name	Actual Impingement Sample Totals	Actual Impingement Sample Totals (g)	Actual Impingement Sample Totals (lb)	Estimated Total Impingement (#)	Estimated Total Impingement (g)	Estimated Total Impingement (lb)
Ulvicola sanctaerosae	kelp gunnel	2	3.9	0.01	16	32.3	0.07
Xererpes fucorum	rockweed gunnel	2	34.5	0.08	18	291.8	0.64
Sebastes caurinus	copper rockfish	2	11.7	0.03	13	79.5	0.18
Anoplarchus purpurescens	high cockscomb	1	8.0	0.02	6	46.9	0.10
Artedius notospilotus	bonyhead sculpin	1	10.5	0.02	6	58.3	0.13
Brachyistius frenatus	kelp surfperch	1	12.0	0.03	6	77.2	0.17
Clinocottus spp.	sculpins	1	3.1	0.01	8	23.7	0.05
Clupea pallasii	Pacific herring	1	16.8	0.04	7	111.2	0.25
Echeneis naucrates	sharksucker	1	463.1	1.02	7	3,113.6	6.86
Embiotocidae unid. (juv.)	surfperches	1	-	-	8	-	-
Eopsetta exilis	slender sole	1	0.1	<0.01	7	0.7	<0.01
Gillichthys mirabilis	longjaw mudsucker	1	4.6	0.01	7	30.7	0.07
Gobiesox spp.	clingfishes	1	0.8	<0.01	7	5.6	0.01
Heterostichus rostratus	giant kelpfish	1	8.2	0.02	13	102.6	0.23
Hydrolagus colliei	ratfish	1	591.0	1.30	7	3,880.4	8.55
Hyperprosopon anale	spotfin surfperch	1	4.4	0.01	6	28.4	0.06
Hypsoblennius jenkinsi	mussel blenny	1	4.6	0.01	6	27.0	0.06
larval/post-larval fish, unid.	unidentified larval fishes	1	-	-	13	-	-
Lepidogobius lepidus	bay goby	1	0.8	<0.01	7	5.4	0.01
Neoclinus uninotatus	onespot fringehead	1	11.8	0.03	8	95.2	0.21
Orthonopias triacis	snubnose sculpin	1	1.4	<0.01	7	9.5	0.02
Pholididae unid.	gunnels	1	15.2	0.03	5	81.9	0.18
Phytichthys chirus	ribbon prickleback	1	14.5	0.03	6	86.6	0.19
Platichthys stellatus	starry flounder	1	1.8	<0.01	5	9.4	0.02
Psettichthys melanostictus	sand sole	1	1.6	<0.01	6	9.6	0.02
Scomber japonicus	Pacific mackerel	1	-	-	6	-	-
Scorpaena guttata	spotted scorpionfish	1	9.7	0.02	6	58.1	0.13
Sebastes spp. (juv.)	rockfishes	1	2.7	0.01	10	26.1	0.06
Sebastes melanops (yoy)	black rockfish (yoy)	1	4.8	0.01	6	30.9	0.07
Sebastes goodei	chilipepper	1	28.2	0.06	8	227.5	0.50
Sebastes chrysomelas/S. carnatus (yoy)	black-and-yellow/gopher rockfish (yoy)	1	1.4	<0.01	13	17.5	0.04
Sebastes chrysomelas (juv.)	black-and-yellow rockfish (juv.)	1	77	0.17	6	495.4	1.09
Sebastes auriculatus	brown rockfish	1	73.3	0.16	7	492.2	1.09
Stellerina xyosterna	pricklebreast poacher	1	3.3	0.01	7	21.7	0.05
Synchirus gilli	manacled sculpin	1	8.5	0.02	7	55.8	0.12
Triakis semifasciata	leopard shark	1	30.0	0.07	7	204.2	0.45
Xiphister mucosus	rock prickleback	1	84.0	0.19	7	570.8	1.26
	Totals:	10,901	167,423.5	369.10	73,825	1,144,142.3	2522.38

'–' A weight was not collected for this taxon.

** The summary total of all rockfishes collected during impingement surveys is included in this table for comparison purposes; however, the rockfish summary totals are excluded from the table totals, since each rockfish species that was collected appears as an individual entry.

Table 4-3. Total counts and weights of selected macroinvertebrates collected during impingement surveys from September 9, 1999 through September 8, 2000 at the MBPP Units 1–4 intakes combined. Total impingement was estimated by expanding the count and weight for each survey with its cooling water volume over the study period.

Taxon	Common Name	Actual Impingement Sample Totals (#)	Actual Impingement Sample Totals (g)	(lb)	Estimated Total Impingement (#)	Estimated Total Impingement (g)	(lb)
Loligo opalescens	market squid	2,545	5,743.4	12.66	16,814	38,036.7	83.86
Crangon nigricauda	black-tailed bay shrimp	1,105	2,102.8	4.64	7,524	14,279.3	31.48
Portunus xantusii	Xantus' swimming crab	719	13,591.7	29.96	4,834	90,708.3	199.98
Cancer jordani	hairy rock crab	544	1,982.7	4.37	3,898	14,316.2	31.56
Cancer antennarius	brown rock crab	503	10,866.1	23.96	3,894	82,310.1	181.46
Pugettia producta	northern kelp crab	445	3,763.9	8.30	3,209	28,046.9	61.83
Cancer spp.	cancer crabs	419	482.4	1.06	3,142	3,665.6	8.08
Strongylocentrotus purpuratus	purple sea urchin	171	1,023.2	2.26	1,269	7,580.6	16.71
Pugettia richii	cryptic kelp crab	160	182.8	0.40	1,111	1,303.7	2.87
Crangon nigromaculata	spotted bay shrimp	160	360.0	0.79	1,072	2,402.1	5.30
Penaeus californiensis	brown shrimp	158	4,785.6	10.55	1,024	30,773.5	67.84
Loxorhynchus crispatus	moss crab	112	519.0	1.14	763	3,439.6	7.58
Cancer productus	red rock crab	82	1,992.7	4.39	580	13,749.4	30.31
Pachygrapsus crassipes	striped shore crab	59	223.5	0.49	388	1,561.8	3.44
Cancer antennarius/C. jordani	cancer crabs	57	283.1	0.62	415	1,866.2	4.11
Cancer gracilis	slender rock crab	55	145.9	0.32	444	1,202.6	2.65
Octopus spp.	octopus	48	2,619.8	5.78	293	16,402.5	36.16
Heptacarpus spp.	tidepool shrimps	46	53.8	0.12	294	337.8	0.74
Crangon spp.	bay shrimp	40	50.0	0.11	270	334.8	0.74
Cancer anthonyi	yellow crab	38	278.0	0.61	264	1,955.4	4.31
Cancer magister	Dungeness crab	35	399.3	0.88	248	3,033.4	6.69
Pachycheles rudis	thickclaw porcelain crab	34	98.9	0.22	211	599.5	1.32
Pandalus spp.	unidentified shrimp	18	13.7	0.03	154	125.2	0.28
Crangon franciscorum	Franciscan bay shrimp	17	25.5	0.06	100	150.6	0.33
Pachycheles pubescens	pubescent porcelain crab	12	34.6	0.08	75	213.2	0.47
Loxorhynchus spp.	spider crabs	9	27.1	0.06	61	160.1	0.35
Cancer magister/gracilis	cancer crabs	9	14.1	0.03	75	121.7	0.27
Pugettia spp.	kelp crabs	7	11.6	0.03	47	70.1	0.15
Lophopanopeus spp.	black-clawed crabs	7	22.4	0.05	58	192.7	0.42
Alpheus clamator	twistclaw pistol shrimp	7	11.2	0.02	46	76.3	0.17
Scyra acutifrons	sharp-nosed crab	6	20.3	0.04	43	144.8	0.32
Pelia tumida	dwarf crab	5	12.8	0.03	31	76.7	0.17
Pachycheles spp.	porcelain crabs	4	5.4	0.01	28	38.9	0.09
Hippolytidae unid.	Hippolytid shrimps	4	2.9	0.01	33	23.4	0.05
Podochela hemphilli	Hemphill's kelp crab	4	5.6	0.01	32	50.2	0.11
Spirontocaris spp.	broken-back shrimp	3	4.6	0.01	18	27.0	0.06
Pugettia gracilis	graceful kelp crab	3	2.0	<0.01	21	13.0	0.03
Hemigrapsus nudus	purple shore crab	2	0.8	<0.01	16	7.7	0.02
Pandalus platyceros	spot shrimp	2	83.1	0.18	16	567.6	1.25
Pandalopsis dispar	sidestriped shrimp	2	8.6	0.02	14	58.7	0.13
Pandalus danae	dock shrimp	2	8.8	0.02	14	59.9	0.13
Palaemon macrodactylus	oriental shrimp	2	1.4	<0.01	12	8.4	0.02
Upogebia pugettensis	blue mud shrimp	2	19.1	0.04	12	117.8	0.26
Hemigrapsus oregonensis	yellow shore crab	1	3.5	0.01	7	24.1	0.05
Strongylocentrotus franciscanus	red sea urchin	1	0.4	<0.01	11	4.4	0.01
Mimulus foliatus	spider crab	1	1.5	<0.01	6	9.0	0.02
Majidae	spider crabs	1	-	-	7	-	-
Alpheus spp.	pistol shrimp	1	1.6	<0.01	7	10.5	0.02
Panulirus interruptus	California spiny lobster	1	16.7	0.04	7	110.2	0.24
Lophopanopeus leucomanus	black-clawed crab	1	2.1	<0.01	10	20.3	0.04
Pyromaia tuberculata	majid crab	1	1.6	<0.01	7	10.9	0.02
Emerita analoga	mole crab	1	3.3	0.01	7	21.6	0.05
Crangon alaskensis	Alaskan bay shrimp	1	2.2	<0.01	6	12.2	0.03
Heptacarpus palpator	stout bodied shrimp	1	1.1	<0.01	6	6.1	0.01
Heterocrypta occidentalis	elbow crab	1	3.8	0.01	8	30.5	0.07
	Totals:	7,674	51,922.2	114.47	52,949	360,469.4	794.69

'–' A weight was not collected for this taxon.

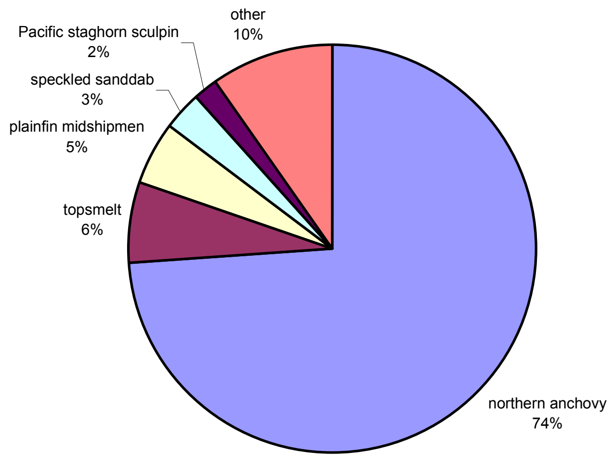
4.5.2 Fishes

Five fish species comprised 90 percent by number of the fishes impinged at MBPP (Units 1 through 4 combined), while seven taxa made up 91 percent of the fishes impinged by weight (Figure 4-1). These fishes are all common to Morro Bay and the surrounding central California coast (Fierstine et al. 1973, Horn 1980, Behrens and Sommerville 1982, Tenera 2000). Most are commonly found in bays (e.g., silversides) and over sandy bottom habitats (e.g., flatfishes and rays), but a few are more typically found either over high relief benthic habitats (cabezon) or in more open ocean settings (e.g., Pacific sardine and northern anchovy). These fishes also generally correspond to the most abundant fish taxa recorded in the previous MBPP impingement study (Behrens and Sommerville 1982) with the exception of shiner perch (mainly newborns) and bocaccio rockfish YOY that were both impinged in greater abundance in the previous study. Numbers and biomass of these fishes impinged during the 1999 – 2000 weekly collections and estimates of their impingement rates are presented in Appendix H.

For the purpose of this report, the impinged fishes considered important at MBPP and consequently used to estimate impingement effects are those species that comprised approximately the top 90 percent by number or weight and co-occurred in both categories. Selecting taxa impinged in both high numbers and in high biomass assures that we are assessing taxa whose populations are most likely to be affected by impingement losses. In particular, three fish species are impinged in both high numbers and biomass at MBPP: northern anchovy (ranked 1st by both number and biomass), topsmelt (ranked 2nd by number and 3rd by biomass), and plainfin midshipman (ranked 3rd by number and 4th by biomass). The thornback ray (ranked 2nd by biomass) was ranked 12th by number and was not included in the impingement assessment. Among these, only the northern anchovy is targeted commercially in a small (2 boats) bait fishery in Morro Bay while topsmelt are occasionally taken by recreational fishers (CDFG unpubl. fishery data). Combined, the three species analyzed comprise approximately 85 percent by number and 66 percent by weight of all fishes impinged at MBPP during the study. Detailed impingement results for these three fishes are presented in the following sections.

In addition to detailing results for the three fishes that were impinged in both high numbers and biomass, the following sections also contain impingement assessments for other recreationally or commercially important taxa (speckled sanddab, Pacific sardine, rockfishes, and cabezon) that were impinged in either high numbers or biomass. Two of the most abundant taxa by number (speckled sanddab [4th] and Pacific staghorn sculpin [5th]) were not as abundant by weight as some of the other taxa (e.g., California thornback ray [2nd], California bat ray [5th], cabezon [6th], and Pacific sardine [7th]) that were impinged at larger sizes, but in smaller numbers (ranked by number 12th, 19th, 11th, and 9th, respectively). Detailed impingement results are also presented for rockfishes (ranked 8th by number) because they represent the most important recreational and commercial fishery in the Morro Bay area. The rockfishes impinged consisted of numerous species that were combined into a single complex for analysis purposes.

a) Number



b) Biomass

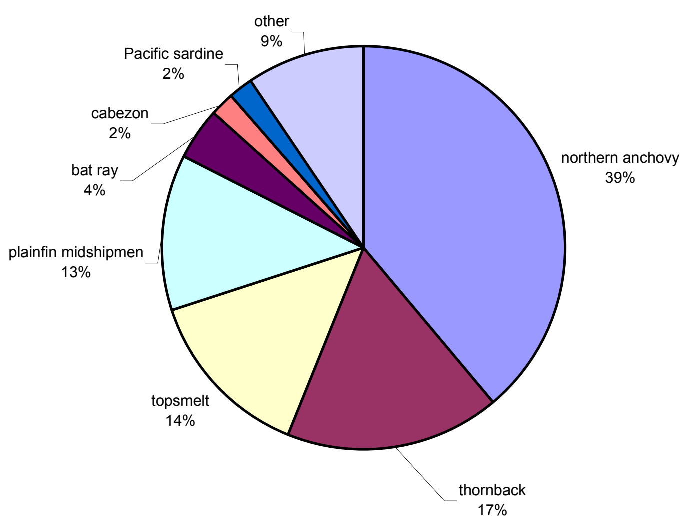
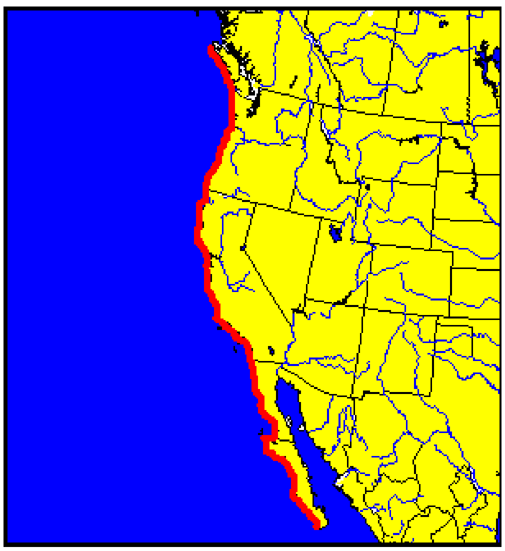


Figure 4-1. Percent taxonomic composition of fishes impinged in the Morro Bay Power Plant cooling water intakes (Units 1 – 4 combined) determined by a) number impinged (#/m^3) and b) biomass impinged (g/m^3).

4.5.2.1 Northern anchovy *Engraulis mordax*



Distribution map for northern anchovy

Range: From British Columbia to southern Baja California.

Life History: Size: to 229 mm (9 in.); Size at maturity: 152 mm (6 in.); Fecundity: spawn 2 to 3 times a year, releasing from 2,700 to 16,000 eggs per batch; Life span: to 7 years.

Habitat: Pelagic; found in surface waters down to depths of 300 m (1,000 ft).

Fishery: Commercial fishery for reduction, human consumption, live bait, dead bait.

The northern anchovy is one of nine to eleven species of the approximately 139 fishes in the family Engraulididae (the anchovies) that occur in the California Cooperative Oceanic Fisheries Investigations (CalCOFI) study area (Moser 1996). The CalCOFI study area covers more than one million square kilometers between the Oregon-California border and the tip of Baja California extending from around 3 – 400 nautical miles offshore (Moser 1996). Other representatives of this family that occur in central California waters are the deepbody anchovy *Anchoa compressa*, slough anchovy *Anchoa delicatissima*, and the anchoveta *Centengraulis mysticetu*s (Miller and Lea 1972, Eschmeyer et al. 1983, Love et al. 1996).

Three sub-populations of northern anchovy are recognized and managed separately along the Pacific coast of the United States (Lo 1985, PFMC 1990, 1998, Love 1996). The northern sub-population occurs from the northern limit of their range in British Columbia south to San Francisco, the central sub-population occurs from San Francisco to northern Baja California, and the southern sub-population is found along the southern coast of Baja, the southern limit for this species. They range from the surface to depths of over 300 m (1,000 ft) (Love 1996). Northern anchovy eggs and larvae have been collected 480 km (298 mi) from shore (Hart 1973) and the adults can exhibit extensive movements within their range (Love 1996). They tend to occur closer to the shoreline in the summer and fall and move offshore during the winter (Hart 1973).

Reproductive activity also varies within their range. Northern anchovy off southern and central California can reach sexual maturity by the end of their first year at 110 – 130 mm (4.3 – 5.1 in.) TL, with all individuals maturing by four years of age and 152 mm (6 in.) TL (Hubbs 1925, Pike 1951, Clark and Phillips 1952, Daugherty et al. 1955, Hart 1973); off Oregon and Washington they do not mature until their third year (Love 1996). Northern anchovy are multiple spawners. In southern California, anchovy spawn year-round with peaks during late winter to spring (Love 1996, Moser 1996). In Oregon and Washington, spawning can occur from mid-June to mid-August (Love 1996). During the peak of the spawning season, females can spawn every six to eight days (Schlotterbeck and Connally 1982, Love 1996). Spawning normally occurs at night in the upper layers of the water column (Hart 1973). An early estimate of northern anchovy fecundity (Baxter 1967) indicates an annual range of 20,000 – 30,000 eggs per female. More recent data from Love (1996) indicate that females can release from 2,700 – 16,000 eggs per batch, with annual fecundity as high as 130,000 eggs in southern California and around 35,000 eggs per year in northern populations. Parrish et al. (1986) indicate that total annual fecundity from the first to the fourth-plus spawning seasons ranges from 32,514 to 322,957 eggs per female, respectively. The eggs hatch within two – four days, depending on the water temperature, and release 2.5 – 3.0 mm (0.10 – 0.12 in.) long relatively undeveloped larvae (Hart 1973, Moser 1996). Larvae begin schooling at 11 – 12 mm (0.4 – 0.5 in.) and transform into juveniles at 35 – 40 mm (1.4 – 1.6 in.) in approximately 70 days (Hart 1973).

Northern anchovy in the central sub-population are harvested commercially in Mexico and California for human consumption, live bait, dead bait, and other 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). Although northern anchovy are fished throughout the state, commercial landings are usually made in San Francisco, Monterey, and Los Angeles. A few small landings are made at local ports (Starr et al. 1998). The average annual landing from 1990 – 1998 is 2.7 MT/year (CDFG unpubl. data).

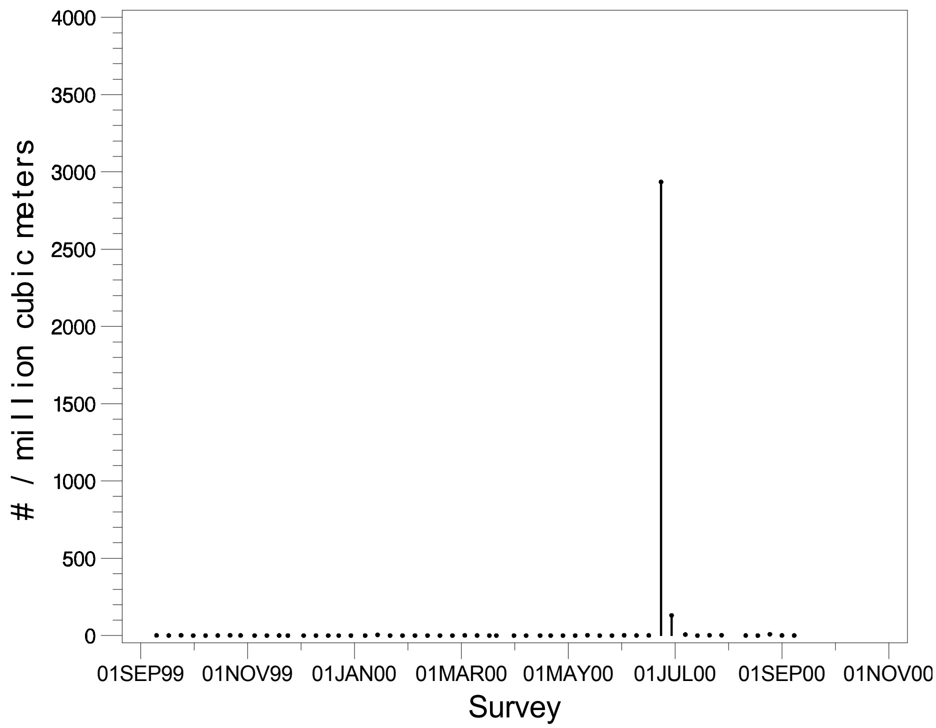
Impingement Results

A total of 8,063 northern anchovy weighing 65 kg (143 lb) was collected during the impingement study at MBPP (Table 4-2). Approximately 97 percent (7,794 individuals) of the total northern anchovy impinged were collected during a single survey on June 22, 2000 (Figure 4-2). Most of the individual fish (6,921) and anchovy biomass collected during the survey were from the Units 3 and 4 intake (the southern most intake structure). The next largest collection occurred during the following week and comprised two percent of the total northern anchovy impinged (Units 1 through 4 combined). Other occurrences of northern anchovy in the collections ranged from 1 to 12 individuals for Units 1–4 combined; however, northern anchovy were not collected in most surveys. Northern anchovy impingement over the study period expanded by cooling water intake volume was estimated to be approximately 54,000 anchovy weighing 434 kg (958 lb) (Table 4-2).

Northern anchovy measured from impingement samples at MBPP ranged in length from 31 to 145 mm (1.2 to 5.7 in.) SL, and as many as 70 percent by number could have been sexually mature (Figure 4-3). Approximately 50 percent of the anchovy impinged were less than 90 mm (3.5 in.) SL, and presumably the age (one year) of first reproduction (Hart 1973). About half of the northern anchovy off California are mature by two – three years and 130 mm (5.1 in.) SL (Pike 1951). Approximately 15 – 20 percent of the northern anchovy impinged at MBPP had attained the size of 50 percent maturity. All northern anchovy are sexually mature by four years and 150 mm (5.9 in.) SL (Hubbs 1925, Clark and Phillips 1952, Daugherty et al. 1955). None of the measured northern anchovy impinged at MBPP had attained this size.

Northern anchovy have consistently ranked as one of the most abundant taxa near the entrance of Morro Bay and at the MBPP intake structures. They ranked first in both numerical abundance and biomass in this study. Northern anchovy ranked 2nd in abundance and 3rd in biomass in the previous 1977-78 MBPP impingement study (Behrens and Sommerville 1982). In Fierstine et al.'s (1973) collection Zone II, which roughly corresponds to the MBPP intake structure, northern anchovy numerically dominated the collection between January 1968 and December 1970 and were present from March – July. From the CDFG otter trawl surveys that began in 1992, northern anchovy ranked 4th in overall numerical abundance and 6th at their Station 2 (located near the MBPP intakes; see Appendix I for a summary of CDFG Morro Bay otter trawl data). Even Horn (1980) sampling far south of Morro Bay harbor entrance near Baywood Park found that northern anchovy comprised a sizable portion (approximately 11 percent) of the fishes collected in bag seines. Thus, northern anchovy appear to be a dominant fish species in the Morro Bay system, although perhaps more prominently so near the MBPP intakes and harbor entrance.

a)



b)

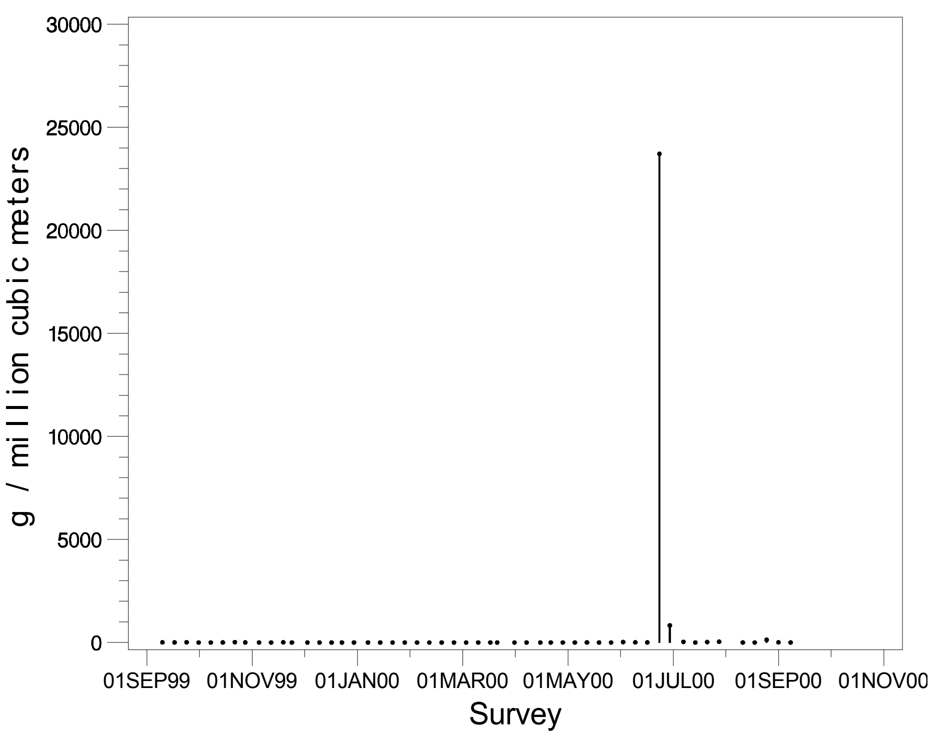


Figure 4-2. Northern anchovy *Engraulis mordax* (n=8,066) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6$ m^3) and b) biomass per million m^3 ($g/10^6$ m^3): September 1999 – September 2000.

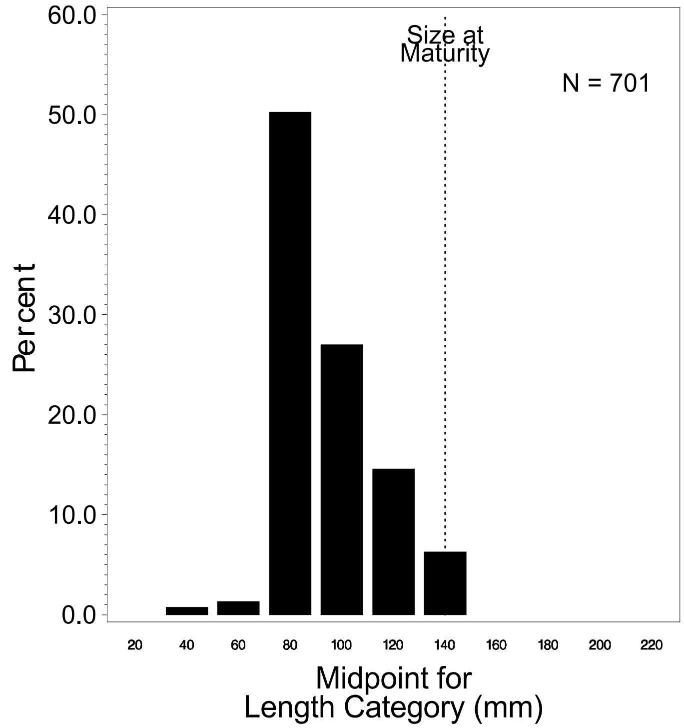
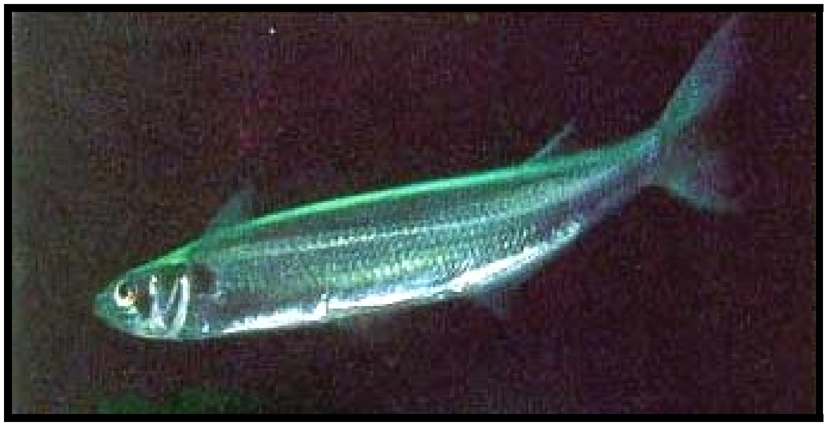
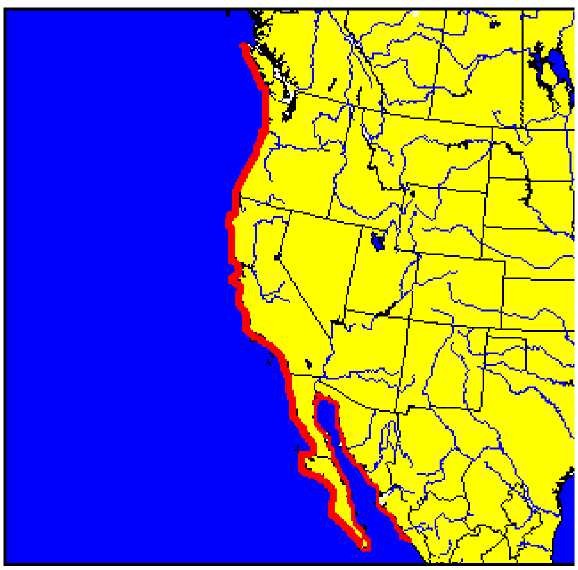


Figure 4-3. Length frequency distribution for northern anchovy *Engraulis mordax* (*n*=701) impinged at the MBPP cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

Length at maturity source: Clark and Phillips 1952, Daugherty et al. 1955, Hubbs 1925.

4.5.2.2 Topsmelt *Atherinops affinis*





Distribution map for topsmelt

Range: From Vancouver Island, British Columbia to the Gulf of California.

Life History: Size: to 368 mm (14.5 in.); Size at maturity: 152 to 203 mm (6 to 8 in.); Fecundity: 200 to 1,000 eggs.

Habitat: Surface dwellers, estuaries to offshore waters.

Fishery: Incidental commercial; recreational.

Topsmelt, along with jacksmelt and grunion, belong to the family Atherinidae (silversides). These schooling fishes are found from the Gulf of California to Vancouver Island, British Columbia (Miller and Lea 1972), occasionally extending as far north as the 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 are a schooling fish (Hart 1973, Allen 1982, Moyle and Cech 1988) occurring primarily nearshore in bays, estuaries, and near kelp beds (Carlisle et al. 1964, Gregory 1992, Moser 1996). They are usually found near the surface (Hobson et al. 1981, Allen 1982), although they may be seen as deep as 9 m (30 ft) (Love 1996). Topsmelt are often the most abundant fishes in estuaries (Allen 1982, Ambrose and Meffert 1999), but are also found in kelp canopies, along sandy beaches, and at times, offshore (Limbaugh 1955, Quast 1968, Wang 1986, Emmett et al. 1991, Love 1996). They are tolerant of a wide range of salinities and can also live in fresh and brackish water (Carpelan 1955, Fronk 1969, Moyle 1976, Emmett et al. 1991, DeLeon 1999).

Topsmelt are oviparous (Matarese et al. 1989, Emmett et al. 1991, Love 1996, Moser 1996) multiple spawners (Fronk 1969, Wang 1986, Love 1996, DeLeon 1999). They mature between one and three years of age (Schultz 1933, Carpelan 1955, Turner 1960, Fitch and Lavenberg 1975, DeLeon 1999) and live from six – nine years (Ruagh 1976, Wang 1986, Matarese et al. 1989, Emmett et al. 1991, Gregory 1992). Size at first maturity is approximately 152 mm (6 in.) (Love 1996) although smaller mature topsmelt have been reported (Schultz 1933, Carpelan 1955, Turner 1960, Emmett et al. 1991, DeLeon 1999). Females produce between 200 – 1,000 eggs per season (Love 1996) spawning primarily at night (Love 1996) in bays, estuaries, and lagoons (Emmett et al. 1991). Large clusters of eggs are formed and attach to algae, grasses, and other aquatic plants (Fronk 1969, Fitch and Lavenberg 1975, DeLeon 1999) via adhesive filaments fixed to the egg chorion (Breder and Rosen 1966, Feder et al. 1974, Ruagh 1976, White et al. 1984, Gregory 1992).

Impingement Results

A total of 693 topsmelt weighing 23 kg (51 lb) was collected during the 1999 – 2000 impingement study at MBPP (Table 4-2). Approximately 92 percent (636 individuals) of the total topsmelt impinged were collected during a single survey on February 24, 2000 (Figure 4-4). Most of those fish (568 individuals) were collected from the Units 3 and 4 intake. The fish from this survey also comprised the majority of the topsmelt biomass (grams of fish) impinged during the study period. Topsmelt impingement for the study period was estimated as approximately 4,100 fish with a total weight of approximately 138 kg (303 lb) (Table 4-2).

Topsmelt were impinged in the MBPP CWIS over an array of lengths ranging from 11 – 220 mm (0.4 – 8.7 in.) SL (Figure 4-5). Size at first maturity reported in Love (1996) is approximately 152 mm (6 in.) SL. Other sources report topsmelt maturing from 100 – 110 mm (3.9 – 4.3 in.) SL and one year old (Carpelan 1955, DeLeon 1999) to 120 mm (4.7 in.) and two years old (Schultz 1933, Turner 1960, Emmett et al. 1991). Based on the smallest reported size at first maturity, 95 percent of the topsmelt impinged at MBPP could have been sexually mature. The unimodal distribution reflected in the topsmelt length frequency histogram reflects one or possibly two year-classes of fish ranging from two to three years in age based on their lengths (Schultz 1933, Turner 1960, Emmett et al. 1991).

Topsmelt are common within Morro Bay and have been consistently abundant over the last three decades. They ranked 4th in numeric abundance between 1968 and 1970 in Fierstine et al.'s (1973) collection Zone II which roughly corresponds to the area of the MBPP intake structures. Topsmelt were also abundant in the previous impingement study conducted at the MBPP (Behrens and Sommerville 1982). No topsmelt were collected in the CDFG otter trawls conducted at Station 2 close to the MBPP intakes, but this is not surprising considering that topsmelt school in the water column while otter trawls are fished along the bottom. Note that Fierstine et al. (1973) used a variety of collecting techniques including otter trawls (e.g., hook-and-line, spearfishing, and beach seines). Horn (1980), using bag seines in southern Morro Bay, found that topsmelt numerically dominated his catch and also comprised the majority of the biomass collected (i.e., ranked 1st in both categories). In this study, topsmelt ranked 2nd by number and 3rd by biomass at the MBPP intakes.

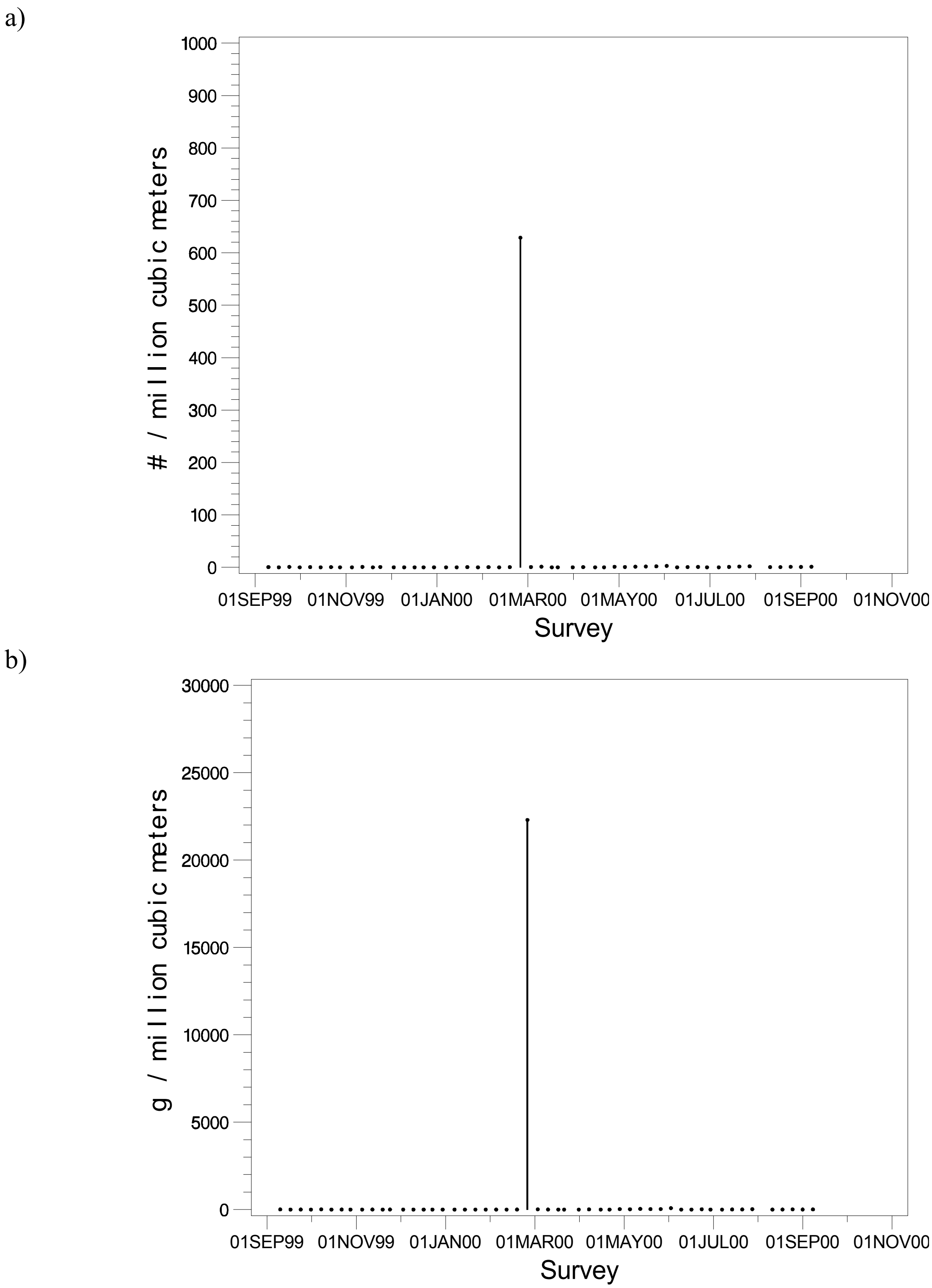


Figure 4-4. Topsmelt *Atherinops affinis* (n=693) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6$ m^3) and b) biomass per million m^3 ($g/10^6$ m^3): September 1999 – September 2000.

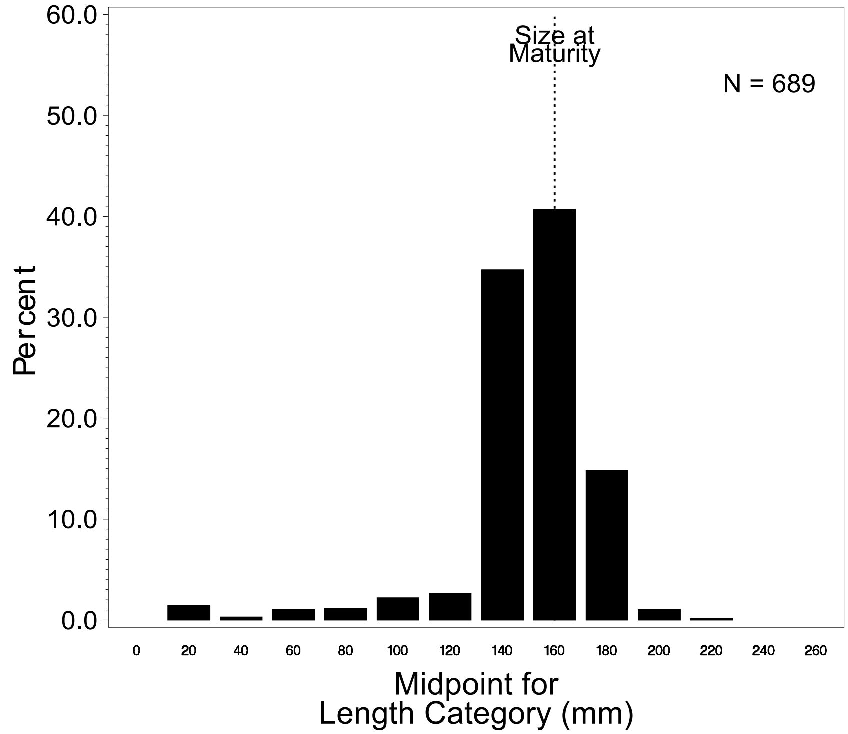
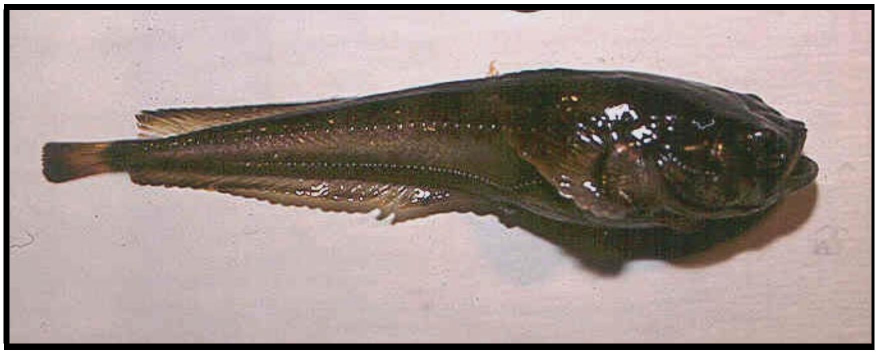


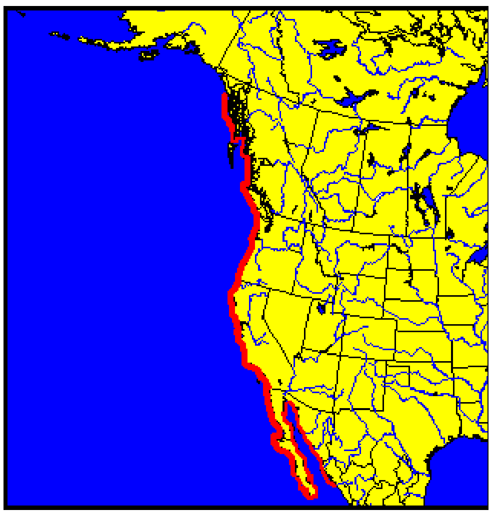
Figure 4-5. Length frequency distribution (*n*=689) and length at first maturity for topsmelt *Atherinops affinis* impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

Length at maturity (approximately 152 mm [6 in.] SL). Source: Love 1996

4.5.2.3 Plainfin midshipman *Porichthys notatus*



Photographer: Dan Dugan



Distribution map for plainfin midshipman

Range: From Sitka, Alaska to the Gulf of California.

Life History: Size: to 38 cm (15 in.); Size at maturity: 140 mm (5.5 in.), some males at 89 mm (3.5 in.); Age at maturity: 2 years; Fecundity: 80 to 500 eggs per spawn; Life span: at least 7 years.

Habitat: Sand and mud bottom, found intertidally to 366 m (1,200 ft).

Fishery: Some commercial trapping in San Francisco Bay bait fishery, no recreational fishery.

The plainfin midshipman belongs to the order Batrachoidiformes comprised of the family Batrachoididae, or toadfishes, containing three subfamilies with 19 genera and 69 species (Nelson 1994). These occur commonly along both coasts of North America (Moyle and Cech 1988) as well as Africa, Europe, southern Asia, and Australia (Nelson 1994). The family is represented in the California Current region by five species, one of which is common in the vicinity of Morro Bay (Miller and Lea 1972, Moser 1996). Plainfin midshipman *Porichthys notatus* is common north of Point Conception while the other California species (specklefin midshipman *P. myriaster*) is common south of Point Conception.

The plainfin midshipman is distributed from Sitka, Alaska south to Bahía Magdalena, Baja California Sur (Miller and Lea 1972, Eschmeyer et al. 1983, Moser 1996). The species is most common from Vancouver Island, British Columbia south, although they are scarce between Cape Flattery, Washington and Northern California (Love 1996). Plainfin midshipman occur from the intertidal zone to depths of 366 m (1,200 ft) (Lamb and Edgell 1986) but are most abundant between 46 and 137 m (151 and 449 ft) (Love 1996).

Adult plainfin midshipman are generally found buried in sand and mud substrata during the day, but are often observed hovering off the bottom or moving about at night (Fitch and Lavenberg 1975, Lamb and Edgell 1986). They spawn in shallow water within tidal limits (Hubbs 1920), in tidewaters of rocky shores (Greene 1924), and in shallow intertidal coastal waterways and bays (Hart 1973, Wang 1986). Adults move from deep water into the intertidal zone to spawn from May – August in central California and from May – September off Santa Barbara (Love 1996, Moser 1996). A female midshipman produces between 80 and 200 eggs per season (Love 1996) that are attached to the underside of rocks or in burrows and guarded by the male through both the egg and attached larval phases (Fitch and Lavenberg 1975, Lamb and Edgell 1986, Wang 1986, Moser 1996). However, this fecundity estimate may be low since Fitch and Lavenberg (1975) note that specklefin midshipman deposit from 200 – 400 or more eggs per spawn and Moser (1996) indicates that a typical plainfin midshipman nest contains 200 – 500 eggs. Larval plainfin midshipman remain attached in the nest until they reach the juvenile stage and are released (Moser 1996). Most individuals mature in two years at a length of approximately 140 mm (5.5 in.), although some males are mature at 89 mm (3.5 in., Love 1996). Plainfin midshipman attain a maximum length of about 380 mm (15 in.) and are thought to live for at least seven years (Lamb and Edgell 1986, Love 1996).

Plainfin midshipman are not commercially targeted in Morro Bay or in surrounding areas. They are commercially trapped in San Francisco Bay for striped bass bait (IEP 2000), but no similar fishery exists in Morro Bay. Plainfin midshipman are often caught incidentally in encircling nets (e.g., lampara) and in shrimp nets (Lamb and Edgell 1986).

Impingement Results

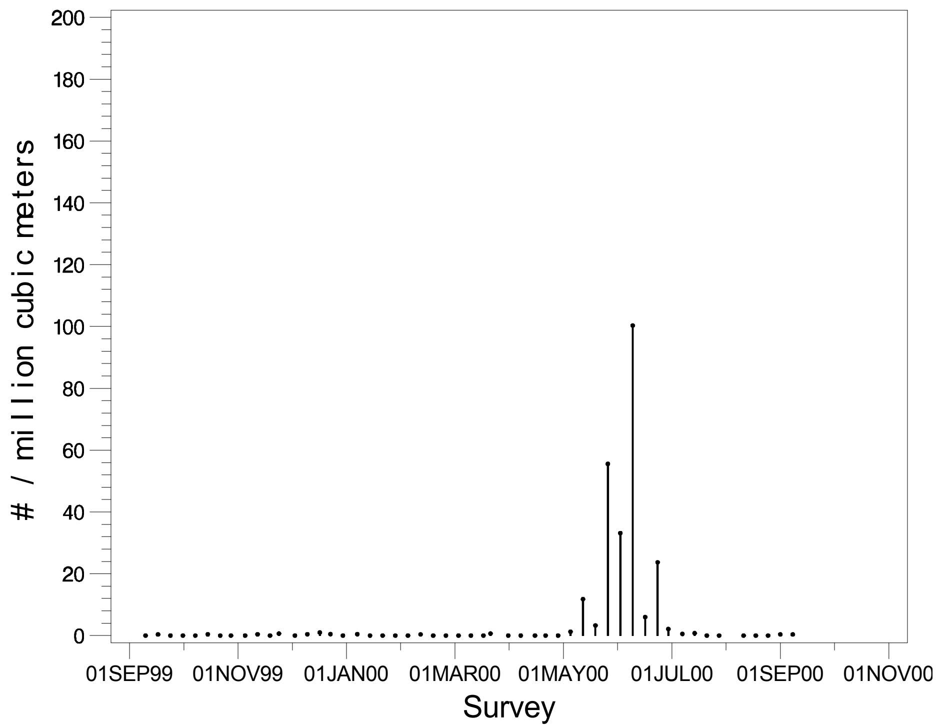
A total of 543 plainfin midshipman weighing approximately 21 kg (47 lb) was collected during the impingement study at MBPP (Table 4-2). The fish were most abundant in May and June 2000 (Figure 4-6) corresponding to reported timing of inshore migration and subsequent spawning (Love 1996, Moser 1996). The majority of the midshipman were collected from the Units 3 and 4 intake. Impinged biomass of plainfin midshipman followed numeric abundance trends. Plainfin midshipman impingement for the study period was estimated as approximately 3,900 individuals weighing about 153 kg (336 lb) (Table 4-2).

The plainfin midshipman impinged at MBPP ranged in length from 30 – 282 mm (1.2 – 11.1 in.) SL and were comprised of immature and sexually mature individuals (Figure 4-7).

Approximately two percent of the plainfin midshipman impinged were at or below the reported (Love 1996) length at first maturity (89 mm [3.5 in.]). The majority of the measured individuals (45 percent) were sexually mature (at or near 140 mm [5.5 in.]) (Love, 1996). Given that plainfin midshipman migrate to bays and estuaries to spawn from May – September (Lamb and Edgell 1986, Love 1996, Moser 1996) when they were impinged in greatest abundance, it is not surprising that the majority of the individuals impinged were sexually mature. Eggs hatch approximately two – three weeks after spawning and larvae remain attached to the nest until detaching as juveniles (16 – 19 mm [0.63 – 0.75 in.]) (Moser, 1996) about one month later (Aurora 1948, Hart 1973). However, few subadults (5 individuals ranging from 30 – 42 mm [1.2 – 1.7 in.] SL) were collected at the MBPP intakes during this study.

The abundance of plainfin midshipman appears to vary spatially and temporally in Morro Bay. Fierstine et al. (1973) collected two plainfin midshipman between 1968 and 1970 in their collections from Zone II, which roughly corresponds to the location of the MBPP intakes. A total of 18 plainfin midshipman were collected in CDFG otter trawls from 1992 – 1999 at Station 2 near the MBPP intakes. They ranked 3rd in number and 4th in biomass in this impingement study. Plainfin midshipman also figured prominently (4th in abundance and 1st in biomass) in the previous impingement study at MBPP (Behrens and Sommerville 1982). Horn (1980) however did not collect plainfin midshipman at his study location in southern Morro Bay.

a)



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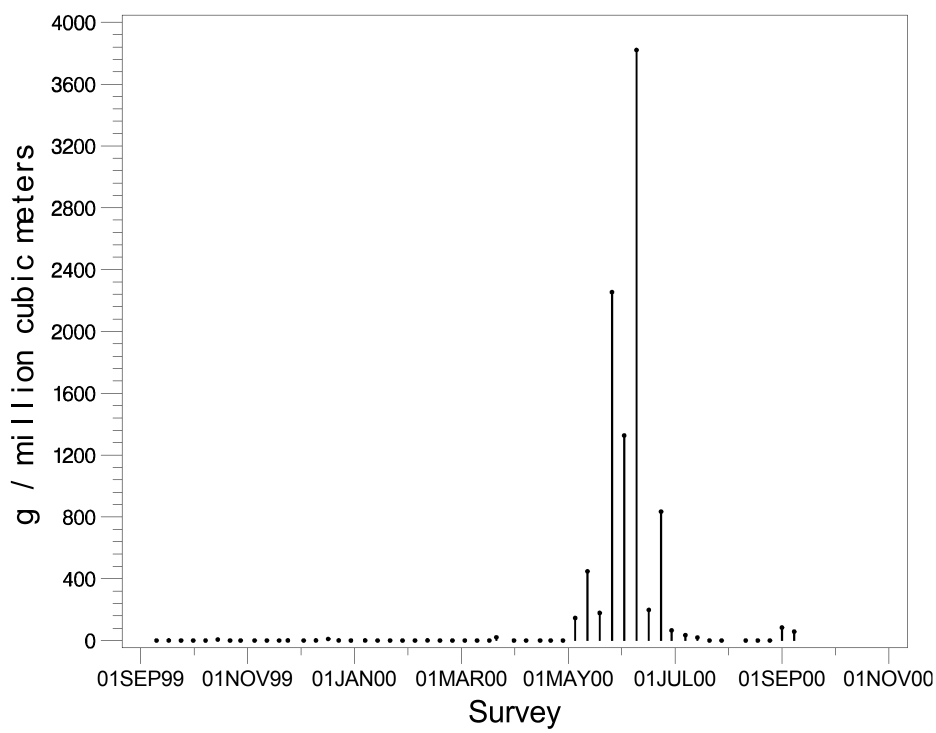


Figure 4-6. Plainfin midshipman *Porichthys notatus* (n=542) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6$ m^3) and b) biomass per million m^3 ($g/10^6$ m^3): September 1999 – September 2000.

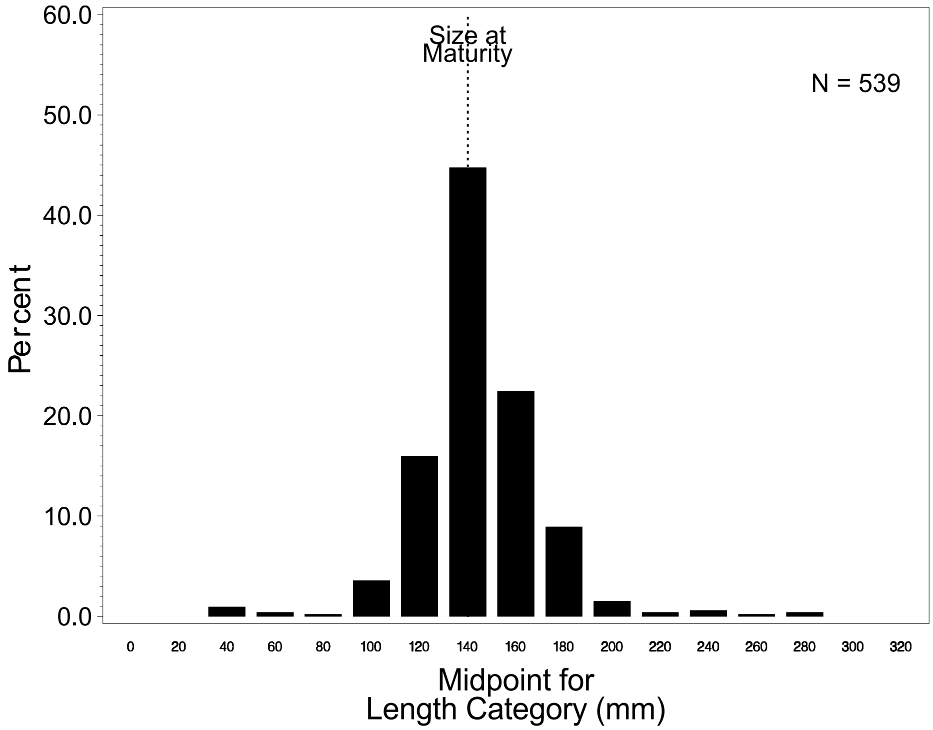
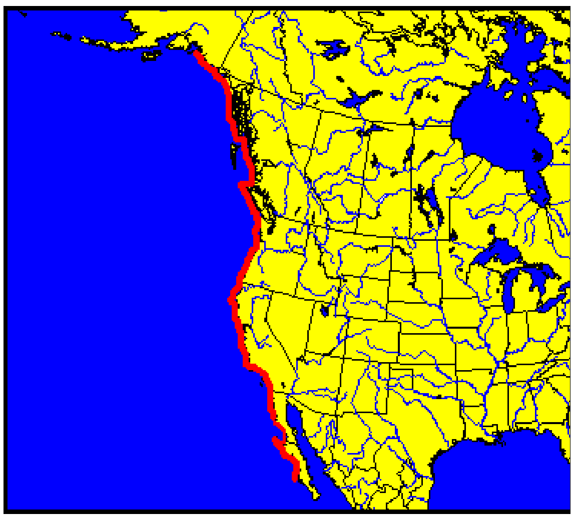


Figure 4-7. Length frequency distribution (*n*=539) and length at 100 percent maturity for plainfin midshipman *Porichthys notatus* impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000. Source for length at 100 percent maturity: Love 1996.

4.5.2.4 Speckled Sanddab *Citharichthys stigmaeus*

Photographer: Dan Dugan



Distribution map for speckled sanddab

Range: From Montague Island, Alaska to Magdalena Bay, Baja California.

Life History: Size: to 17 cm (6.7 in.); Size at maturity: 70 mm (2.75 in.); Fecundity: 1,000 to 6,000 eggs per batch, up to three batches per year; Life span: may live over 4 years.

Habitat: Sandy bottoms from nearshore to depths of 600 m (2,000 ft).

Fishery: No commercial fishery; caught recreationally.

Two species of sanddabs are common in California, the speckled sanddab *Citharichthys stigmaeus* and Pacific sanddab *Citharichthys sordidus*. Both species are components of local recreational and commercial fisheries and are usually found over sandy bottoms, with the speckled sanddab generally found in shallow water bays and estuaries (Moser 1996, Rackowski and Pikitch 1989). Sanddab females are oviparous, producing planktonic eggs and larvae (Moser 1996). According to Moser (1996), both species spawn year-round in California coastal waters with the highest larval abundance for speckled sanddab during the period of August – December with a peak in October. In southern California, Goldberg and Pham (1987) found that speckled sanddab spawn from March – October.

Longevity and reproduction have been investigated in both species of sanddabs. Ford (1965) found that female speckled sanddabs begin to spawn in their first year at between 70 – 80 mm

(2.8 – 3.1 in.) and can produce up to three batches of eggs per year. They may produce 1,000 – 6,000 eggs per batch and may live over four years (Ford 1965). Some female Pacific sanddabs first mature at two years (Smith 1936). Half of the older females are mature by three years and all are mature by four years (Aurora 1951). Total life span may be over 11 years (Love 1996). No estimates of annual egg production have been reported. Both species of sanddabs can have extended planktonic durations. Sakuma and Larson's (1995) review reports that speckled sanddab *Citharichthys stigmaeus* larvae may be planktonic up to 324 days. Kendall (1992) found that speckled sanddabs probably settle after 113 – 324 days at a size of about 35 mm (1.4 in.) (Moser 1996).

Impingement Results

A total of 341 speckled sanddabs weighing approximately 1 kg (2.4 lb) was collected during the impingement study at MBPP (Table 4-2). Speckled sanddabs were collected throughout the year, but were most abundant and reached their peak impinged biomass in May and June 2000 (Figure 4-8). This peak may correspond to an inshore migration during summer noted by Love (1996). Speckled sanddab impingement for the study period was estimated to be approximately 2,300 individuals weighing about 8 kg (17 lb) (Table 4-2).

Speckled sanddabs collected during impingement studies ranged in length from 28 – 97 mm SL (1.1 – 3.8 in.) and most (approximately 75 percent) were immature (Figure 4-9). The majority of these (approximately 54 percent) were recently transformed juveniles (Moser 1996). The reported length at first maturity (70 – 80 mm [2.8 –3.2 in.]) corresponds to the first year of growth (Ford 1965). Thus, approximately 25 percent of the speckled sanddabs impinged at MBPP during this study may have been sexually mature.

Speckled sanddabs have been collected in all previous studies at differing levels of abundance. Over the approximately two year study by Fierstine et al. (1973) a total of 75 speckled sanddabs were collected from the five collection zones combined; none were collected from Zone II which incorporates the MBPP intakes. In his study of southern Morro Bay, Horn (1980) collected only three speckled sanddabs during quarterly sampling conducted over one year. In the previous MBPP impingement study (Behrens and Sommerville 1982), sanddabs were collected in measurable abundance. During otter trawl surveys conducted by CDFG from 1992 – 1999, speckled sanddabs were ranked 1st in abundance by number at Station 2 near the MBPP intakes. Numerically, speckled sanddab accounted for 78 percent (7,138 individuals) of the total fishes collected at Station 2 from 1992 – 1999 (CDFG unpubl. otter trawl data). In this study, they were ranked 4th by number and 12th by biomass. Speckled sanddabs appear to be more abundant near the harbor entrance and MBPP intake structures compared with the southern and eastern portions of Morro Bay.

a)

b)

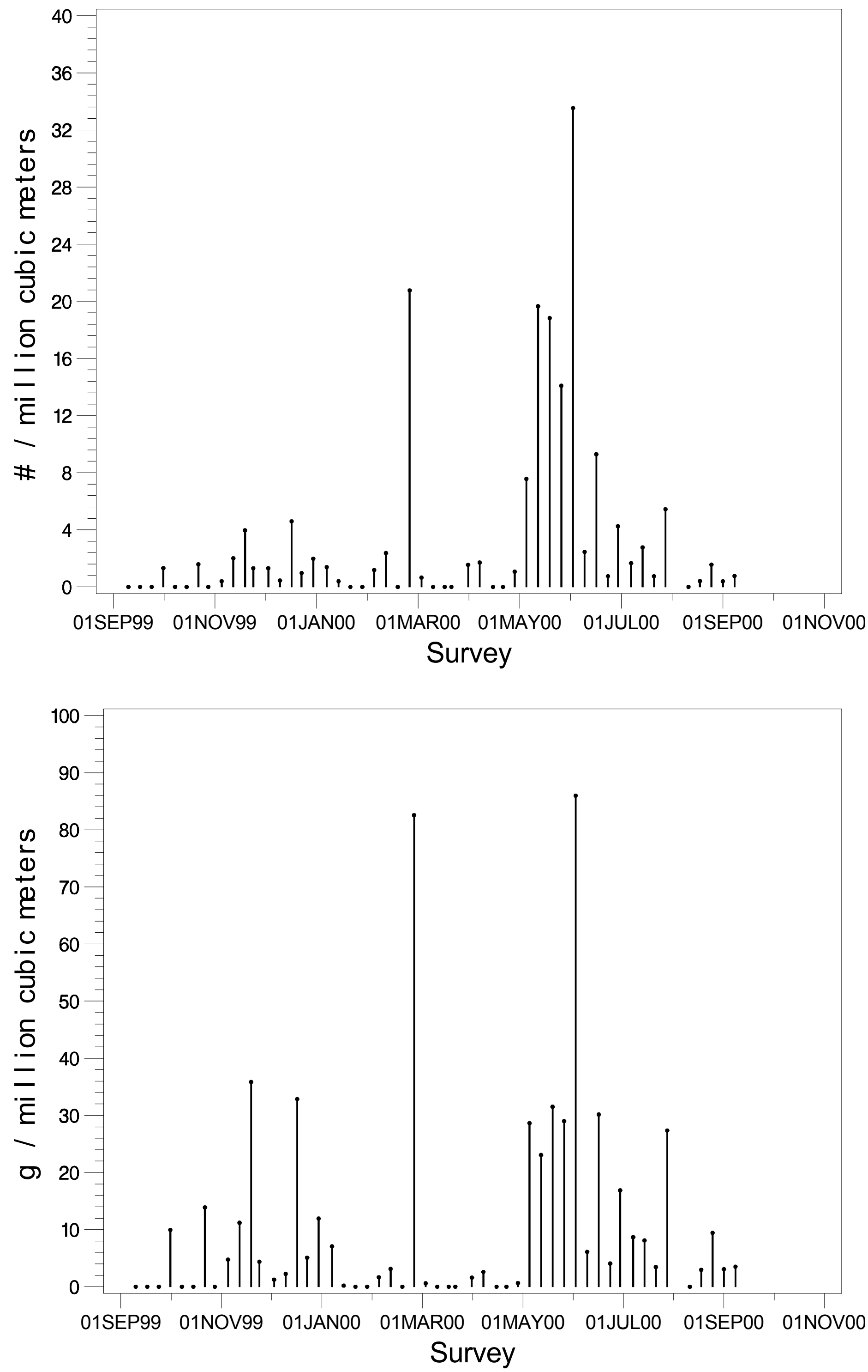


Figure 4-8. Speckled sanddab *Citharichthys stigmaeus* (*n*=341) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 (#/10^6 m^3) and b) biomass per million m^3 (g/10^6 m^3): September 1999 – September 2000.

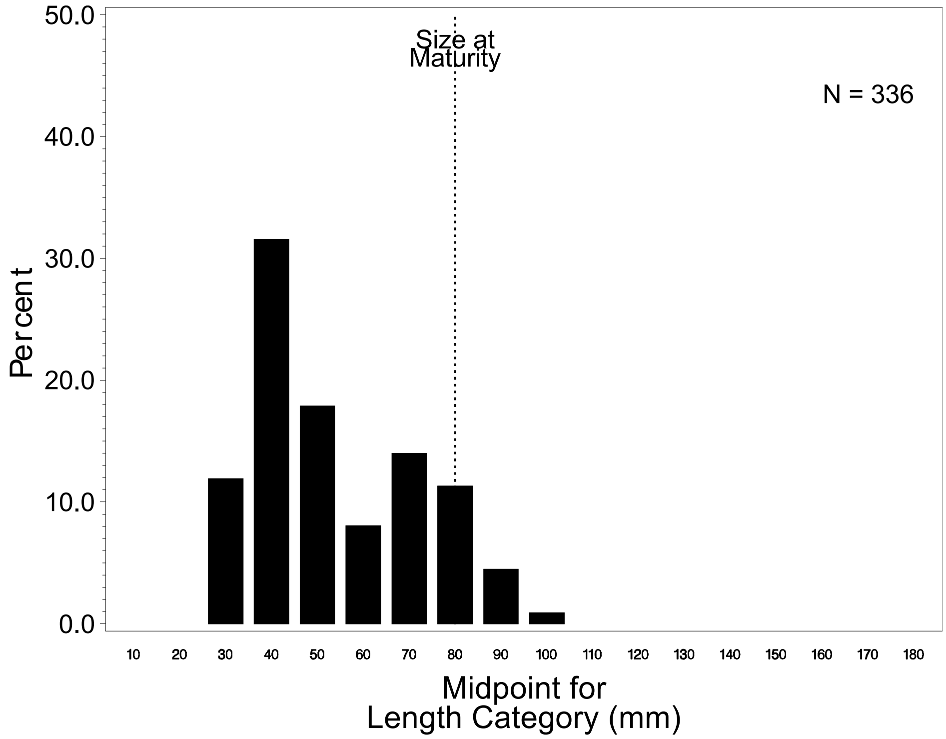
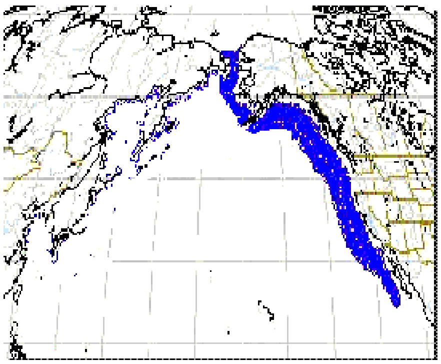


Figure 4-9. Length frequency distribution (*n*=336) and length at first maturity for speckled sanddab *Citharichthys stigmaeus* impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) September 1999 – September 2000.

Length at maturity source: Ford 1965.

4.5.2.5 Pacific sardine *Sardinops sagax*



Distribution map for Pacific sardine

Range: Kamchatka Peninsula, Russia to southeast Alaska to Mexico.

Life History: Size: 413 mm (16.3 in.); Size at maturity: 18 cm to 24 cm (7 to 9.5 in.); Fecundity: 30,000 to 65,000 eggs; Life span: to 13 years.

Habitat: Nearshore to hundreds of miles offshore.

Fishery: Commercial and recreational.

The Pacific sardine is a member of the family Clupeidae (herrings), which is also represented locally by American shad *Alosa sapidissima*, Pacific herring *Clupea pallasii*, threadfin shad *Dorosoma petenense*, and round herring *Etrumeus teres*. The sharp decline of the Pacific sardine population in the mid-1940's led to the demise of the world's largest commercial fishery and to the establishment of the CalCOFI program (originally named the Cooperative Sardine Research Program) in 1947 (Moser 1996). Recently, the CDFG issued a press release (January 15, 1999) indicating that the Pacific sardine resource has now fully recovered. Their most recent stock assessment recommended that the catch quota be increased from the 1998 quota of 43,574 MT to a 1999 harvest of 120,556 MT (Hill et al. in prep.).

Pacific sardine spawn pelagic eggs and larvae year round with a fall/winter minimum and a spring/summer maximum (Moser 1996). Spawning occurs primarily to the south of San Diego (Hart 1973). Reproduction is temperature dependent, and the spawning biomass may move north during El Niño years (Laman and Ehrler 2000). Length at maturity may also be temperature dependent, with females potentially maturing at shorter lengths during the warm phase of El Niño Southern Oscillations (ENSO). For instance, 50 percent of females matured at about 16 cm SL (6 in.) in southern California (Macewicz et al. 1996), but 50 percent of the females reached maturity at about 13 cm SL (5 in.) off Ensenada, Baja California, Mexico during the warm phase of an El Niño (Ahlstrom 1960). Additionally, Hart (1973) indicates longer lengths at maturity for sardines off of Canada (i.e., first maturity at approximately 18 cm [7 in.], 50 percent maturity at approximately 21.5 cm [8.5 in.], and 100 percent maturity at approximately 24 cm [9.5 in.]). Relatively large proportions of fish at age class zero-year have reached maturity in both the Southern California Bight and Monterey Bay (Deriso et al. 1996).

Each year sardines migrate northward early in summer and return south in fall, migrating farther with each year of life (Hart 1973). The timing and extent of these migrations are complex and may be affected by oceanographic conditions. Age stratification of the adult population does appear to occur over a latitudinal gradient, with the larger, older fish occurring farther north (Hart 1973). The adult population off the central coast of California generally consists of young adults (two to four years) that have migrated from the primary spawning grounds in southern California to feeding grounds in local waters (PFMC 1998).

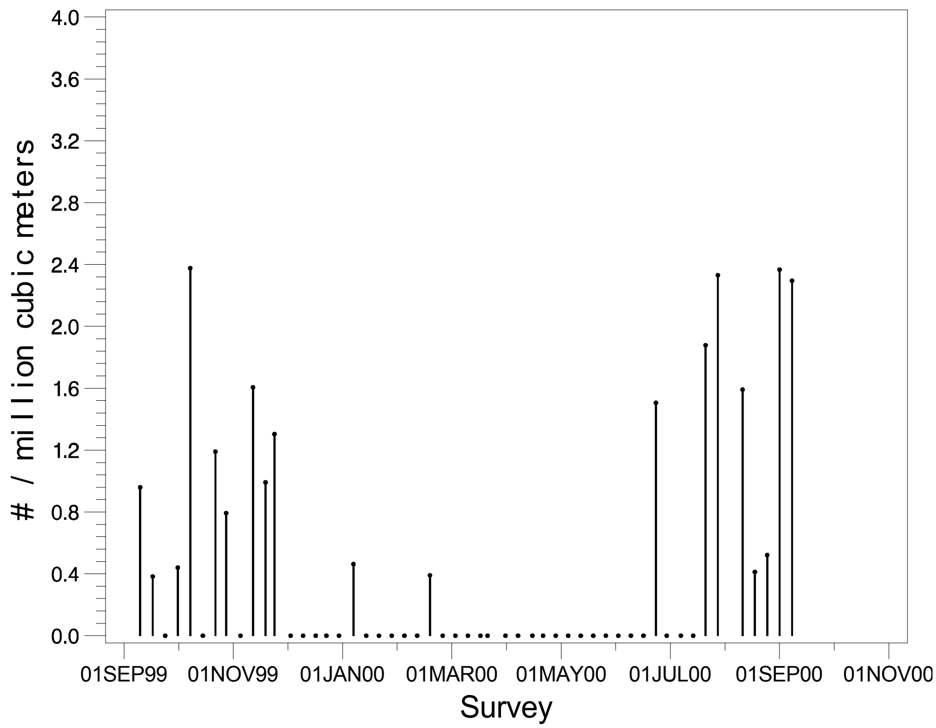
Impingement Results

A total of 57 Pacific sardine weighing approximately 3 kg (7 lb) was collected during the impingement study at MBPP (Table 4-2). These fish were impinged in greatest numbers and biomass in early summer through fall (Figure 4-10). Pacific sardine impingement for the entire study period was estimated to be approximately 420 individuals weighing about 24 kg (54 lb) (Table 4-2). Sardine do not typically spawn in the vicinity of Morro Bay (Hart 1973), but do undergo large scale (Baja California to Canada) movements during their lifetime. The sardines impinged at MBPP are likely relatively young fish that were migrating northward along the coast.

Pacific sardines collected during impingement ranged from 135 – 238 mm SL (approximately 5 – 9 in.) and all were longer than the smallest reported length at first maturity of 13 cm (5 in.) (Hart 1973, Ahlstrom 1960, Macewicz et al. 1996, Figure 4-11). However, sardine do not typically spawn north of Point Conception (Hart 1973) except perhaps in years of elevated water temperatures such as the warm phase of ENSO events (Laman and Ehrler 2000).

Recent stock assessments indicate that Pacific sardine abundance is increasing in the California Current system (Hill et al. in prep.). Previous studies of fishes in Morro Bay do not reflect this increase. Fierstine et al. (1973) collected only two Pacific sardine during the course of their study while Horn (1980) did not collect any. It is unlikely that Horn (1980) would have collected Pacific sardine at his study area which was far removed from the harbor entrance. While no Pacific sardine were collected at CDFG otter trawl Station 2 (near the MBPP intakes) from 1992 – 1999, four individuals ranging from 41 – 44 mm (1.6 – 1.7 in.) were collected at otter trawl Station 4 (back bay) during 1992 (CDFG unpubl. otter trawl data). A few were also recorded from the previous impingement study (Behrens and Sommerville 1982). However, in this study, Pacific sardine ranked 9th by number and 7th by biomass indicating that there likely has been an increase in the local population of Pacific sardine.

a)



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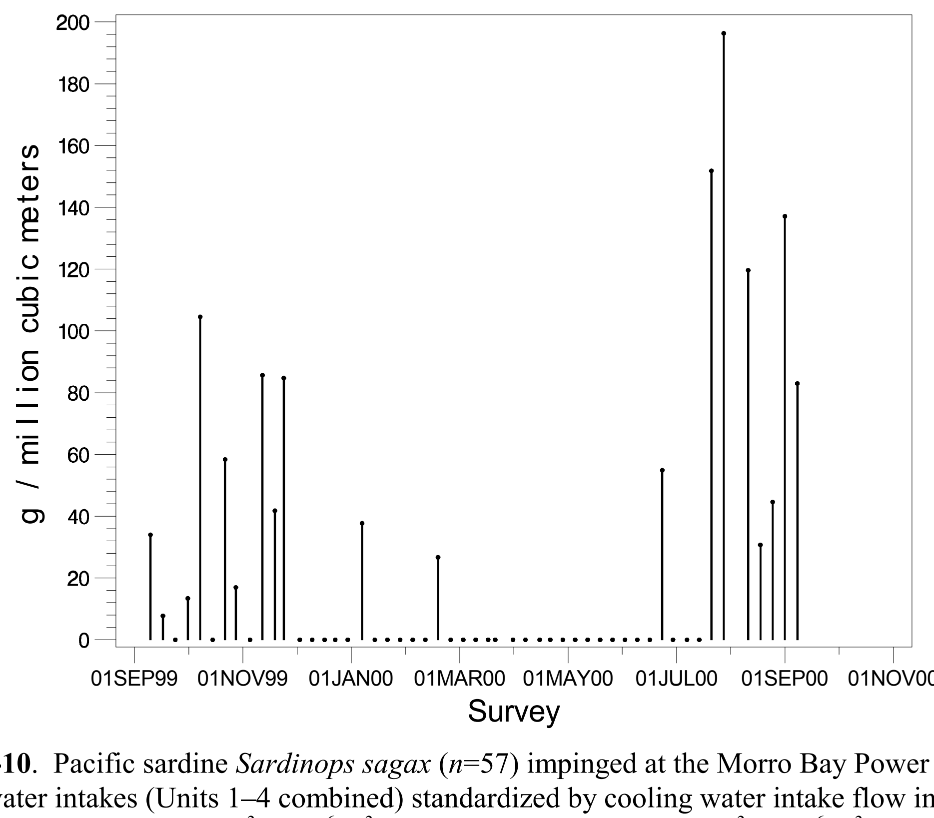


Figure 4-10. Pacific sardine *Sardinops sagax* (n=57) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6\ m^3$) and b) biomass per million m^3 ($g/10^6\ m^3$): September 1999 – September 2000.

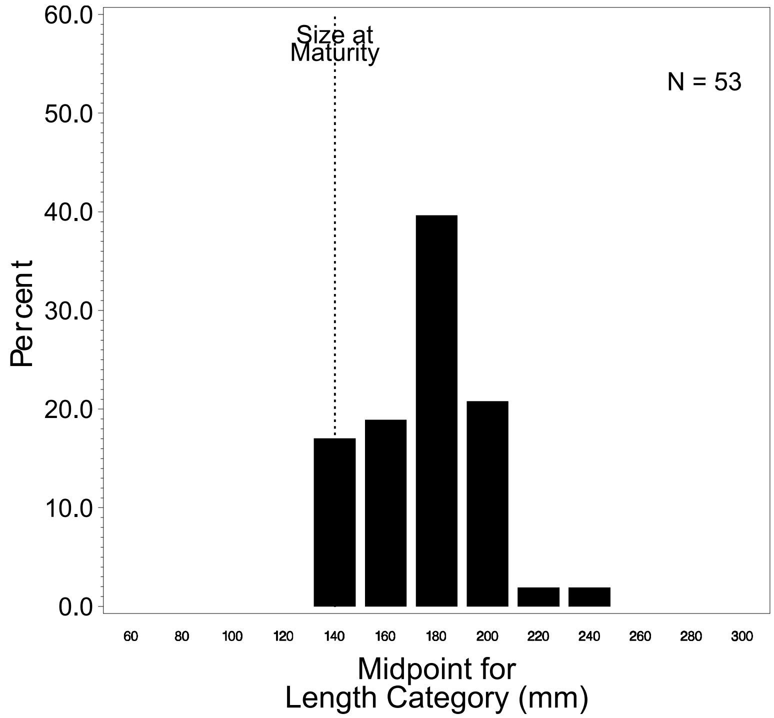
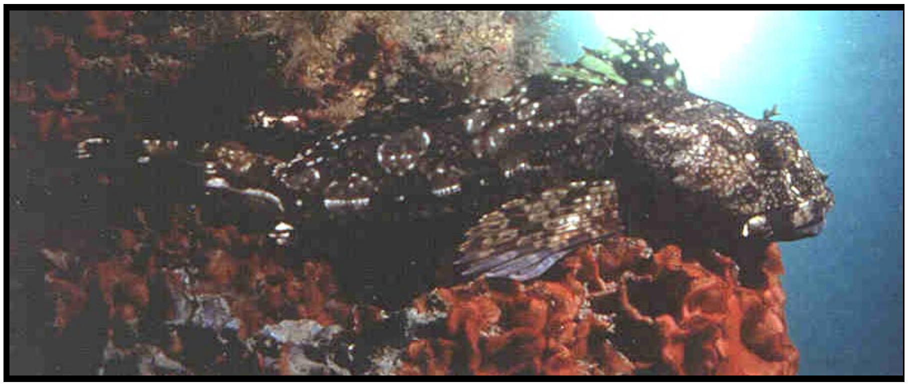


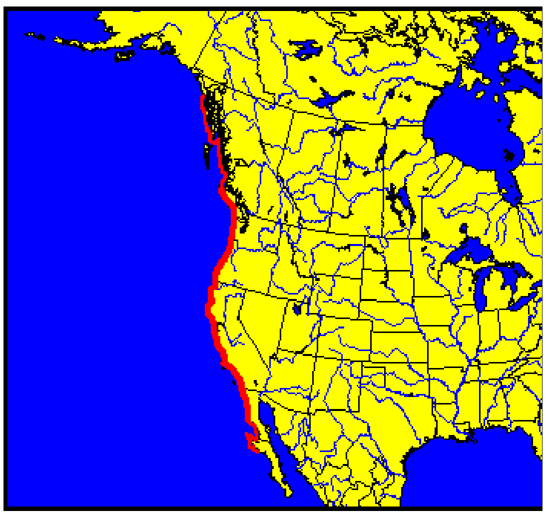
Figure 4-11. Length frequency distribution and length at 50 percent maturity for Pacific sardine *Sardinops sagax* (*n*=53) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

Length at 50 percent maturity source: Ahlstrom 1960, Macewicz et al. 1996.

4.5.2.6 Cabezon *Scorpaenichthys marmoratus*



Photographer: Dan Dugan



Distribution map for cabezon

Range: From Sitka, Alaska to central Baja California.

Life History: Size: to 99 cm (39 in.); Size at maturity: 250 to 480 mm (9.8 to 18.9 in.), at 3 to 5 years; Fecundity: size dependant, 45,000 to 152,000 eggs; Life span: females to 13 years; males to 9 years.

Habitat: Hard bottom, intertidal to 85 m (280 ft).

Fishery: Commercial live fish market; recreational importance.

The cabezon *Scorpaenichthys marmoratus* is a member of the family Cottidae which contains 70 genera and about 115 species in marine and fresh waters in North America (Nelson 1994). It is the largest North American species of marine cottid and occurs over the nearshore continental shelf from depths of 85 m (280 ft) up to the intertidal zone (O'Connell 1953, Matarese et al. 1989). Cabezon are a popular sport fish and are also landed commercially (Fitch and Lavenberg 1971, Lamb and Edgell 1986). Females are oviparous and lay demersal, adhesive eggs in rocky crevices or on algae; males guard the egg nest until the pelagic larvae hatch (Burge and Schultz 1973, Feder et al. 1974, Matarese et al. 1989).

Cabezon have a typical reproductive life history for California current fishes (Parrish et al. 1981). Spawning occurs in California from October to April (Love 1996). Juvenile cabezon were observed to settle in tidepools at around 40 mm (1.6 in.) SL in March off Moss Beach, California (R.R. Harry unpubl. data cited in O'Connell 1953) and possibly three to four months of age. Females begin to mature in their third year between 25 – 48 cm SL (10 – 19 in.) (Fitch and

Lavenberg 1971), and all are mature by year five (Starr et al. 1998). Fecundity for this species has been reported in several sources: 45,000 eggs for a 43 cm (17 in.) SL specimen and 95,000 eggs for a 65 cm (26 in.) SL specimen (Hart 1973); mean fecundity of 48,700 eggs for a 1.4 kg (3.1 lb) female and 97,600 eggs for a 4.6 kg (10 lb) female (O'Connell 1953, Bane and Bane 1971); and up to 152,000 eggs from a 76 cm SL (30 in.) female (Starr et al. 1998). In California, females annually spawn multiple batches of eggs (O'Connell 1953, Hart 1973). Females live to 13 years and males to nine years (O'Connell 1953).

Impingement Results

A total of 45 cabezon weighing approximately 3 kg (7 lb) was collected during the impingement study at MBPP (Table 4-2). Cabezon occurred year-round in impingement samples, except during March and April (Figure 4-12). The greatest biomass of impinged cabezon was recorded during June and September resulting from the collection of a few larger specimens.

Although a few larger individuals were collected, the majority of the cabezon impinged at MBPP were from 39 – 200 mm SL (1.6 – 7.9 in.) and sexually immature (Figure 4-13). Length at first maturity has been reported from the literature as 250 – 480 mm (9.8 –19 in.) and three years of age (Fitch and Lavenberg 1975). Two cabezon collected during this study were of sufficient length to have potentially attained sexual maturity (i.e., 300 mm and 370 mm [11.8 and 14.6 in.] SL). Cabezon impingement over the study period was estimated as 349 individuals weighing about 24 kg (52 lb).

The habitats within Morro Bay are not the high relief rocky habitats where cabezon are typically found. Therefore, it is not surprising that previous studies of fishes in the bay have yielded few cabezon. Fierstine et al. (1973) collected only three cabezon during the course of their study while Horn (1980) did not collect any. Cabezon were collected at Station 2 every year of the otter trawl survey except for 1998. A total of 37 cabezon were collected at Station 2, with the majority (24) collected in 1994 (CDFG unpubl. otter trawl data). A total of three cabezon was also collected at the southernmost back bay CDFG otter trawl station. In this study, cabezon ranked 11th by number and 6th in biomass.

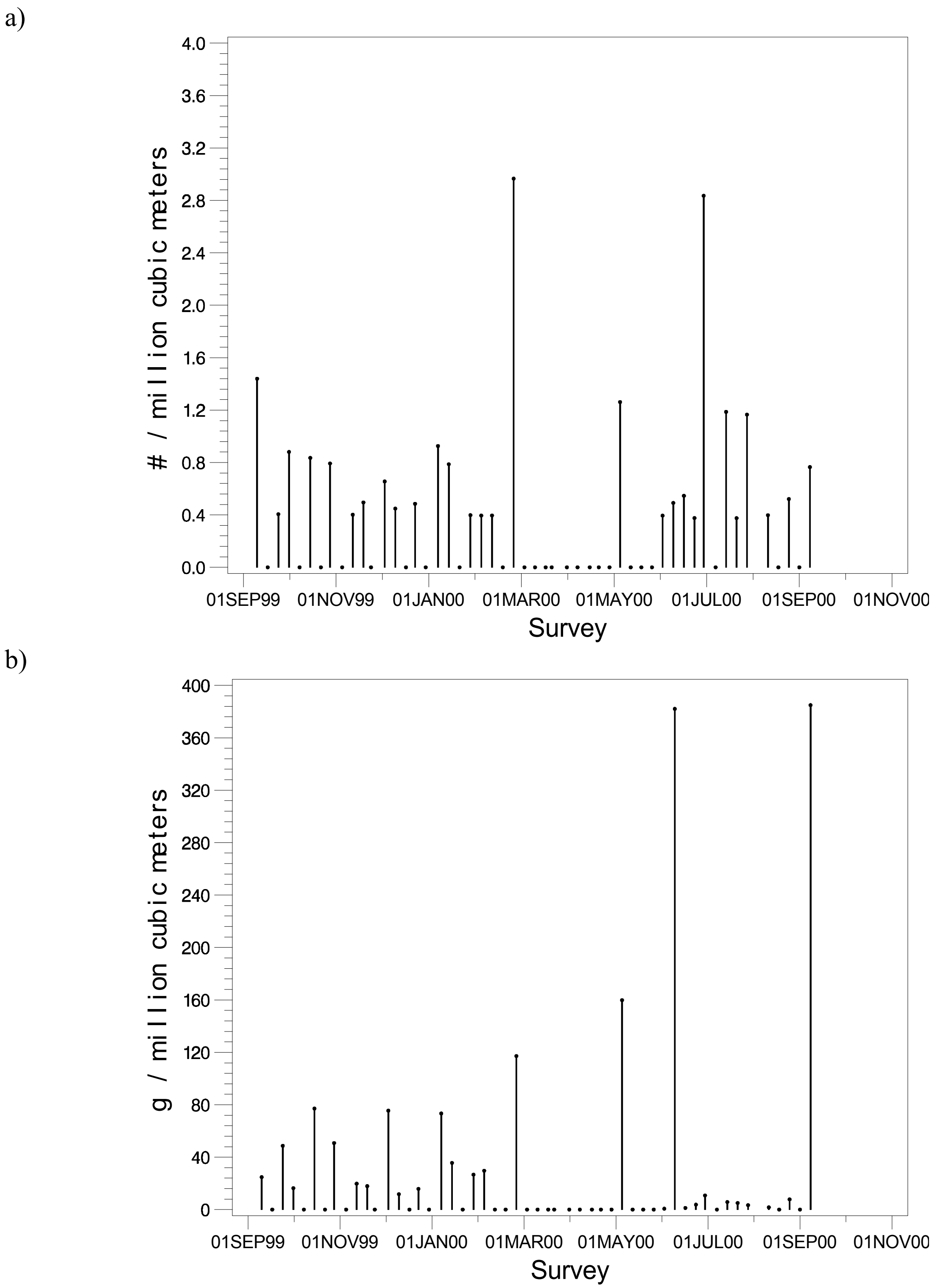


Figure 4-12. Cabezon *Scorpaenichthys marmoratus* (*n*=45) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6$ m^3) and b) biomass per million m^3 ($g/10^6$ m^3): September 1999 – September 2000.

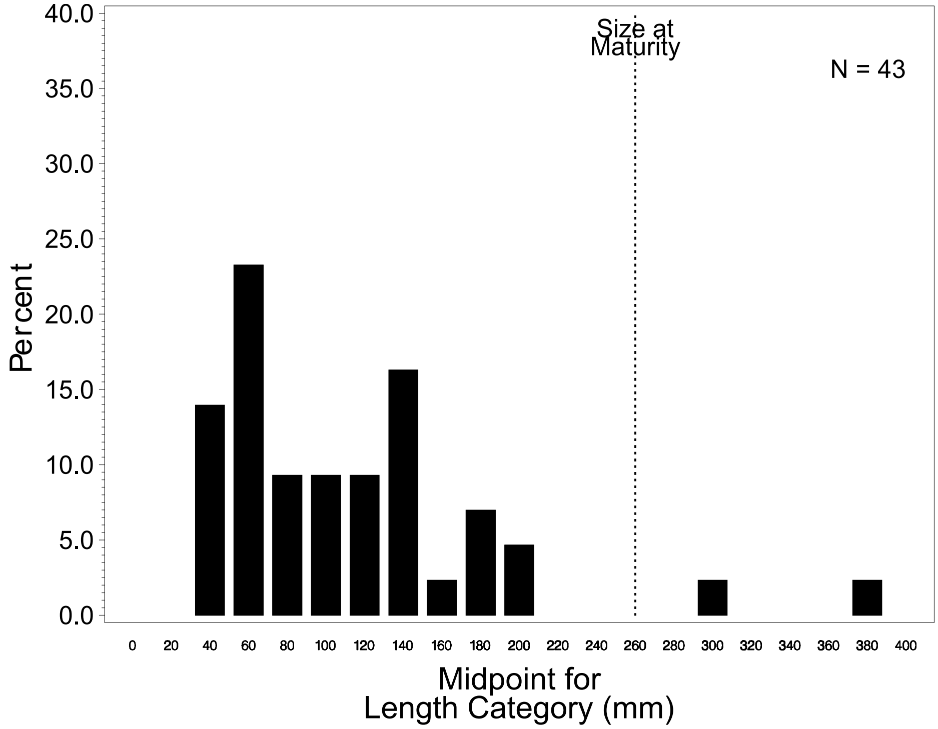


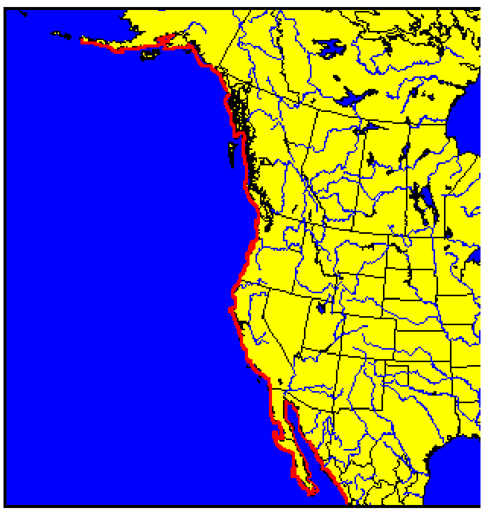
Figure 4-13. Length frequency distribution (*n*=43) and length at first maturity (females) for cabezon *Scorpaenichthys marmoratus* impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

Length at first maturity (females) source: Fitch and Lavenberg 1971.

4.5.2.7 Rockfishes

Yellowtail Rockfish

Photographer: Dan Dugan



Distribution map for *Sebastes* spp. of the Pacific coast of North America

Range**:** At least 59 species off the Pacific coast of North America: Alaska to Mexico.

Life History**:** Reproduction: obligate internal bearers; Fecundity: variable, dependant on species and size; Life span: variable, many are slow growing and long-lived.

Habitat**:** Intertidal to over 610 m (2,000 ft); typically associated with hard substrata.

Fishery**:** Commercial and recreational.

Rockfishes (*Sebastes* spp.) belong to the family Scorpaenidae in the subfamily Sebastinae that contains about 110 species (Nelson 1994). Around 59 species of *Sebastes* occur in the California Current region (Chen 1971, Chen 1975, Miller and Lea 1972, Eschmeyer et al. 1983, Lea et al. 1999) and comprise the largest complex of commercially and recreationally important California marine fish species. Approximately 85 percent of the species occurring in California marine waters are harvested in commercial or sport fisheries (Starr et al. 1998, Lea et al. 1999). Rockfishes are also abundant in nearshore California habitats, comprising a large component of the shallow subtidal fish community, and consequently playing an important trophic and ecological role in these communities. They range from nearshore coastal habitats (e.g., kelp forests) to the continental shelf and slope.

Species identification of the some juvenile rockfishes in the genus *Sebastes* is difficult. Many characters used for identification are shared and many of the species are closely related (Moser et al. 1977, Moser and Ahlstrom 1978, Barsukov 1981, Kendall and Lenarz 1987, Moreno 1993). Consequently, we combined all rockfishes collected in impingement samples into a single taxonomic category for the purpose of these analyses.

Impingement Results

A total of 60 individuals in the family Scorpaenidae weighing approximately 1.4 kg (3 lb) was collected during the impingement study at MBPP (Table 4-2). Rockfishes were most abundant during late November, but were collected throughout the year (Figure 4-14). Much of the rockfish mating activity takes place in the late fall and early winter to produce larvae in the late winter and early spring. This may account for the high impingement abundance observed during late fall in this study. Rockfish impingement expanded by cooling water flow volume over the entire study period was estimated as 448 individuals weighing about 9 kg (21 lb).

Fishes in the family Scorpaenidae were combined into a single complex (Table 4-4) for analysis of impingement abundance. Ten species of rockfishes and one scorpionfish *Scorpaena guttata* were identified during the study and 11 individuals were identified to the generic level (*Sebastes* spp.). In all cases, the average length of the rockfishes impinged at MBPP was less than reported lengths at first maturity.

Rockfishes as a complex have been collected in most of the previous fish surveys of Morro Bay. They were collected by Fierstine et al. (1973) and Behrens and Sommerville (1982). Only four YOY bocaccio were collected during the CDFG otter trawl study from 1992 – 1999. One individual was collected at Station 2 (near the MBPP intakes; CDFG unpubl. otter trawl data). The most notable difference between this study and previous studies is the apparent decrease in the number of bocaccio collected. In Fierstine et al. (1973), bocaccio ranked 6th by number from their surveys. In the previous impingement study at MBPP, bocaccio were one of the most abundant fishes impinged (Behrens and Sommerville 1982). However, in this study bocaccio were ranked 63rd by number and 73rd by biomass represented by a total of two individuals. Bocaccio populations have been declining since the strong year class of 1977 and have also been placed on the International Union for Conservation of Nature and Natural Resources (IUCN) red list for threatened species (MacCall et al. 1999).

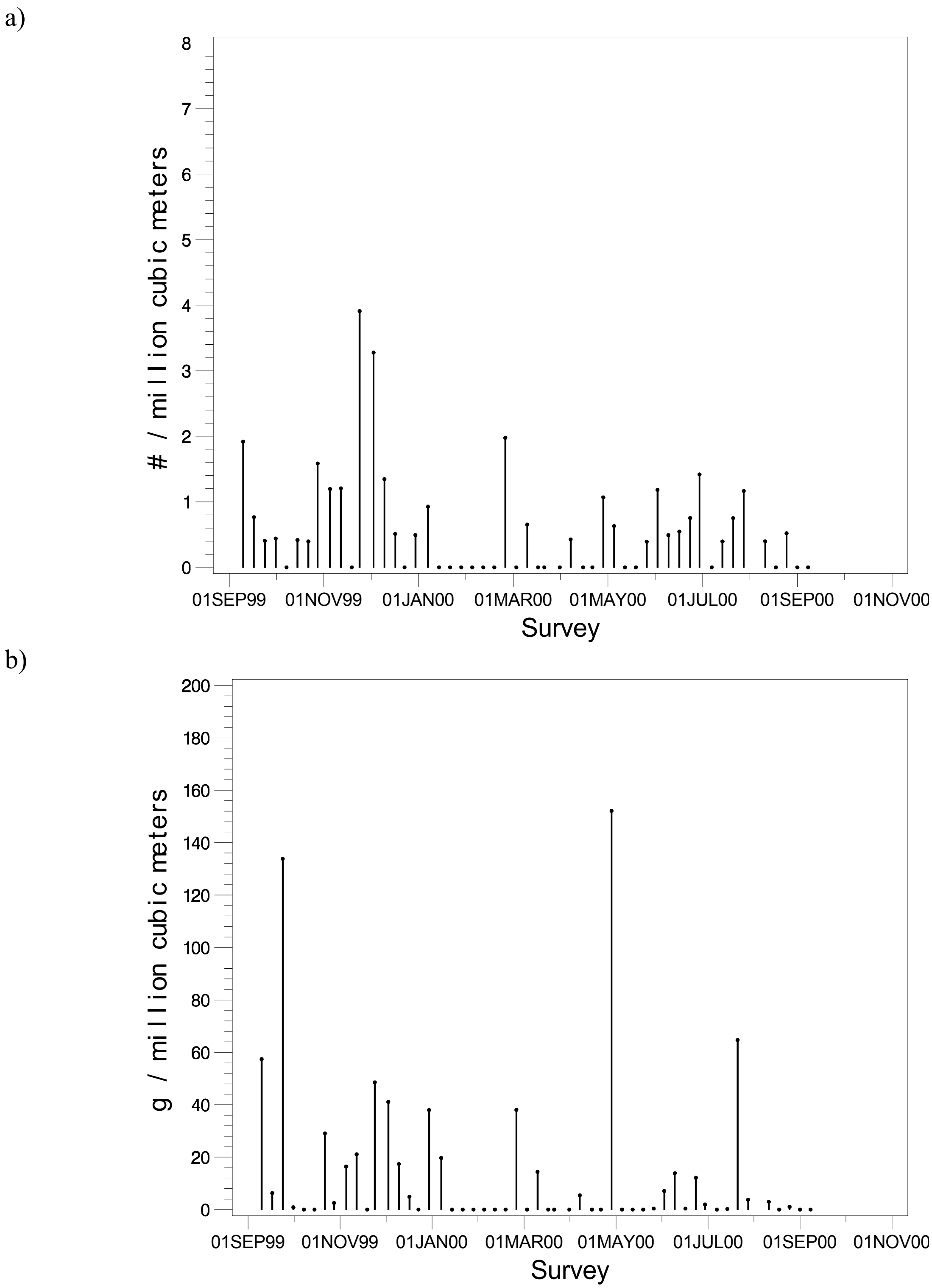


Figure 4-14. Rockfishes (family Scorpaenidae) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6\ m^3$) and b) biomass per million m^3 ($g/10^6\ m^3$): September 1999 – September 2000.

Table 4-4. Scorpaenids impinged from September 1999 – September 2000 at Morro Bay Power Plant cooling water intakes (Units 1–4 combined) with their average length and length at first maturity.

Taxon	Common Name	N	Mean Length (SL mm)	Length at 1st Maturity (mm)
Scorpaena guttata	spotted scorpionfish	1	67	203[a,b]
Sebastes atrovirens	kelp rockfish	7	101	160-240[c,d,e,f]
Sebastes atrovirens (juv.)	kelp rockfish (juv.)	6	99	160-240[c,d,e,f]
Sebastes auriculatus	brown rockfish	1	145	230-260[a,g,h,i,j]
Sebastes carnatus	gopher rockfish	3	83	140-210[c,d,g,k]
Sebastes caurinus	copper rockfish	2	54	300-340[a,c,g,l]
Sebastes chrysomelas	black-and-yellow rockfish	6	78	140-240[c,d,g,j,k,m]
Sebastes chrysomelas/ S carnatus (juv.)	KGB complex juvenile	1	48	
Sebastes goodei	chilipepper	1	125	280-320 [(1) a,s]
Sebastes melanops	black rockfish	8	56	300-450[a,g,n]
Sebastes melanops (yoy)	black rockfish (yoy)	1	62	300-450[a,g,n]
Sebastes paucispinis	bocaccio	2	62	356-420[a,s]
Sebastes rastrelliger	grass rockfish	8	117	220-320[c,i,o]
Sebastes serranoides	olive rockfish	2	40	220-320[a,c,g,p,q,r]
Sebastes spp.	unidentified rockfishes	10	115	
Sebastes spp. (juv.)	unidentified juvenile rockfishes	1	48	
	Total	**60**		

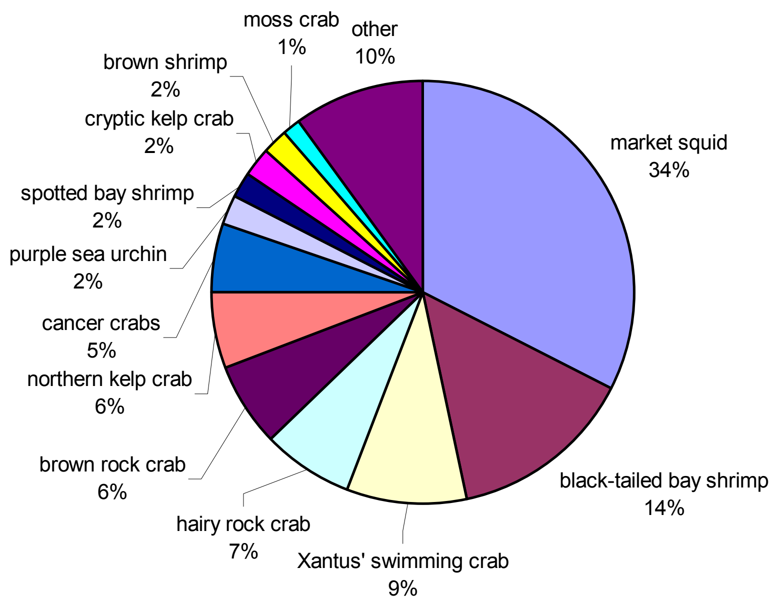
(1) Length at 50 percent maturity
a – Love 1996
b – Love et al. 1987
c – Lea et al. 1999
d – Tenera 2000
e – Romero 1988
f – Coyer 1979
g – Wylie Echeverria 1987
h – Baxter 1999
i – Love and Johnson 1998
j – Reilly et al. 1994
k – Larson 1980
l – Adams 1992
m – Zaitlin 1986
n – Wallace and Taggart 1994
o – Fitch and Lavenberg 1975
p – Love and Westphal 1981
q – Love 1978
r – Miller 1960
s – Starr et al. 1998

4.5.3 Macroinvertebrates

Twelve taxa comprised 90 percent by number of the selected macroinvertebrates impinged at MBPP (Units 1-4 combined) while nine taxa made up greater than 90 percent by weight during the same period (Figure 4-15). Two of the most abundant macroinvertebrates collected during impingement (market squid and Xantus' swimming crabs) are subject to large variations in abundance due to environmental factors (McInnis and Broenkow 1978, Dickerson and Leos 1992, Vojkovich 1998). They occur sporadically in local coastal waters and were not collected in large numbers during the previous impingement study (Behrens and Sommerville 1982), but are abundant when they occur. Market squid *Loligo opalescens* predominated the selected macroinvertebrates impinged; accounting for 34 percent by number and 11 percent by weight of the impingement totals. Xantus' swimming crabs *Portunus xantusii* were typically large when captured explaining their higher contribution to impingement biomass (26 percent) when compared to their abundance (9 percent). Estimates of impingement abundance for selected macroinvertebrate taxa presented in the following sections were calculated by expanding the counts and biomass values for a survey by their corresponding cooling water volumes and totaling the values for all the surveys (Appendix H).

The impinged macroinvertebrates considered important at MBPP and used to estimate impingement effects are those species comprising at least the top 90 percent by number or weight and co-occurring in both categories. In particular, seven species were in the top 90 percent by number and weight: market squid *Loligo opalescens*, black-tailed bay shrimp *Crangon nigricauda*, Xantus' swimming crab *Portunus xantusii*, hairy rock crab *Cancer jordani*, brown rock crab *C. antennarius*, northern kelp crab *Pugettia producta*, and brown shrimp *Penaeus californiensis*. These seven taxa comprise approximately 78 percent by number and 82 percent by weight of the macroinvertebrates impinged at MBPP during the study. Other taxa were either numerically abundant, but relatively small and therefore did not rank high based on biomass (e.g., *Cancer* spp., spotted bay shrimp *Crangon nigromaculata*, and cryptic kelp crab *Pugettia richii*) or were relatively large when collected but occurred rarely (e.g., *Octopus* spp.). Although purple sea urchins *Strongylocentrotus purpuratus* were not impinged in high numbers and biomass, they support an important commercial fishery in California. Therefore, impingement results for this species are also presented.

a) Number



b) Biomass

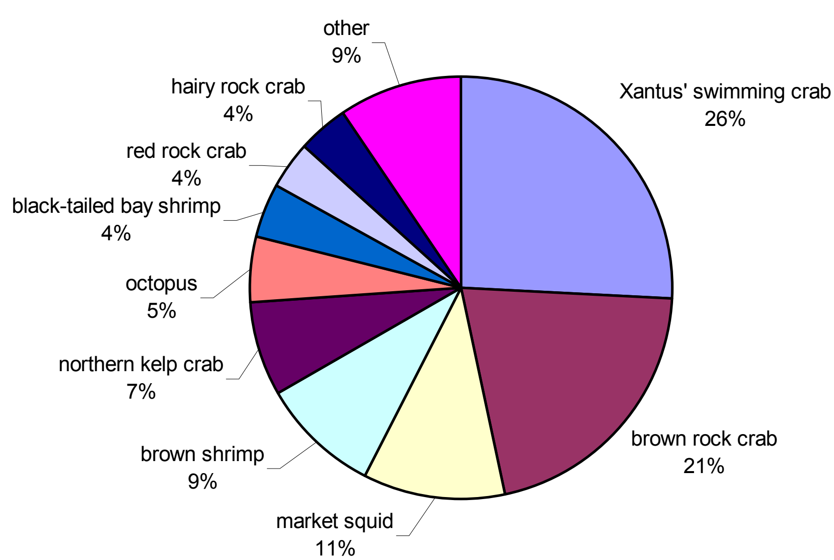
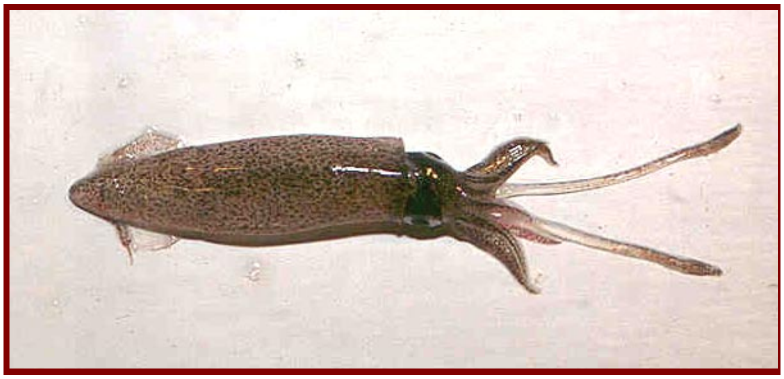
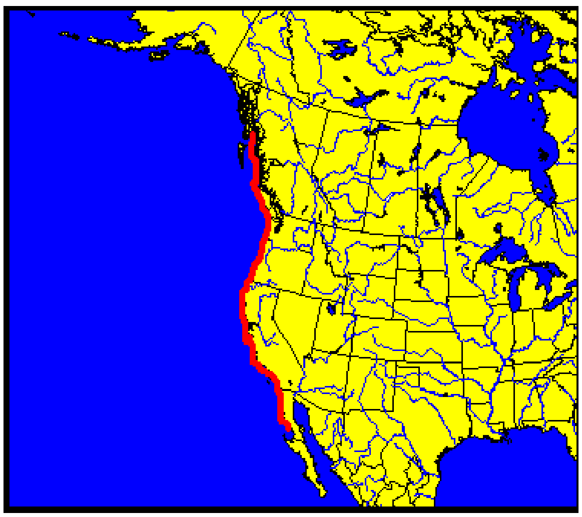


Figure 4-15. Percent taxonomic composition of selected macroinvertebrates impinged at Morro Bay Power Plant's cooling water intakes (Units 1–4 combined) determined by a) number impinged (#/m^3) and b) biomass impinged (g/m^3).

4.5.3.1 Market Squid *Loligo opalescens*



Photographer: Dan Dugan



Distribution map for market squid

Range: From southern Alaska to Isla Guadalupe, Mexico.

Life History: Size: Males to 275 mm (11 in.) (not including tentacles) and females to approximately 200 mm (8 in.); Size at maturity: dorsal mantle lengths as small as 70 to 80 mm (2.8 to 3.1 in.); Fecundity: 180 to 300 eggs encased in a capsule, may extrude 20 to 30 capsules; Life span: less than one year.

Habitat: Pelagic, living in coastal waters but returning to shallow inshore waters to spawn.

Fishery: Commercial, marketed for human consumption or sold as bait.

The market squid is a member of the family Lolinginidae in the order Decapoda that also contains octopus. Market squid range from southern Alaska to Isla Guadalupe, Mexico, and Bahía Asuncíon, Baja California (Morris et al. 1980), but are most common from British Columbia southward (Hochberg and Fields 1980). They are pelagic, living in coastal waters and moving to semi-sheltered bays and other locations with suitable substrata (sand or mud bottoms) to spawn in depths ranging from just below the intertidal down to 180 m (approximately 10 – 540 ft) (Fields 1965, Kato and Hardwick 1975).

Male market squid reach 275 mm (11 in.) dorsal mantle length (DML) not including tentacles, and females attain 200 mm DML (8 in.) (UCLA 1999). Male and female market squid may reach maturity at around 70 – 80 mm DML (approximately 3 in.) in as little as six months (Butler et al. 1999, FWIE 1999). At 15 mm (0.6 in.) DML, squid are reported to be approximately 50 days old. Recent age estimates indicate that the market squid may complete their life cycle in less than one year (Butler et al. 1999).

Market squid spawn year-round from San Francisco to Baja California, but exhibit two spawning peaks annually (Starr et al. 1998). Spawning activity begins in the southern California market squid population in December and continues through March. In Monterey Bay they begin spawning in April and continue through November (McInnis and Broenkow 1978, Hochberg and Fields 1980). Both male and female squid are terminal spawners and die after spawning.

The female produces from 180 – 300 eggs encased in a cylindrical capsule and may extrude 20 to 30 capsules during a spawning event (Starr et al. 1998, FWIE 1999). Recent research on market squid reproduction corroborates reports by Starr et al. (1998) and FWIE (1999) that estimated around 5,500 eggs per spawning female (Macewicz et al. 2000). Egg cases are attached with thin stalks to the bottom substratum (Fields 1965). 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 – 180 m (10 – 590 ft) (FWIE 1999) and the eggs hatch in 15 – 90 days, depending on water temperature (Fields 1965, Yang et al. 1986).

Impingement Results

A total of 2,545 market squid weighing approximately 5.7 kg (12.7 lb) was collected during the impingement study at MBPP (Table 4-3). The majority (73 percent) of the squid were collected from the Units 1 and 2 intake during a single impingement collection survey on June 22, 2000 (Figure 4-16). Impingement biomass also peaked during this same period. Market squid impingement for the entire study period was estimated to be approximately 16,800 individuals weighing approximately 38 kg (84 lb) (Table 4-3).

The length frequency distribution for the market squid *Loligo opalescens* collected during impingement studies ranged from 24 mm to 144 mm (1.0 to 5.7 in.) DML (Figure 4-17). The majority (approximately 80 percent) of impinged market squid were between 30 and 50 mm (1.2 and 2.0 in.) DML. Seven squid measured in this study (less than 2 percent of those measured) were larger than the reported length at maturity (72 – 81 mm [2.8 – 3.2 in.] DML) (Butler et al. 1999, FWIE 1999) indicating that the vast majority of squid impinged were not sexually mature.

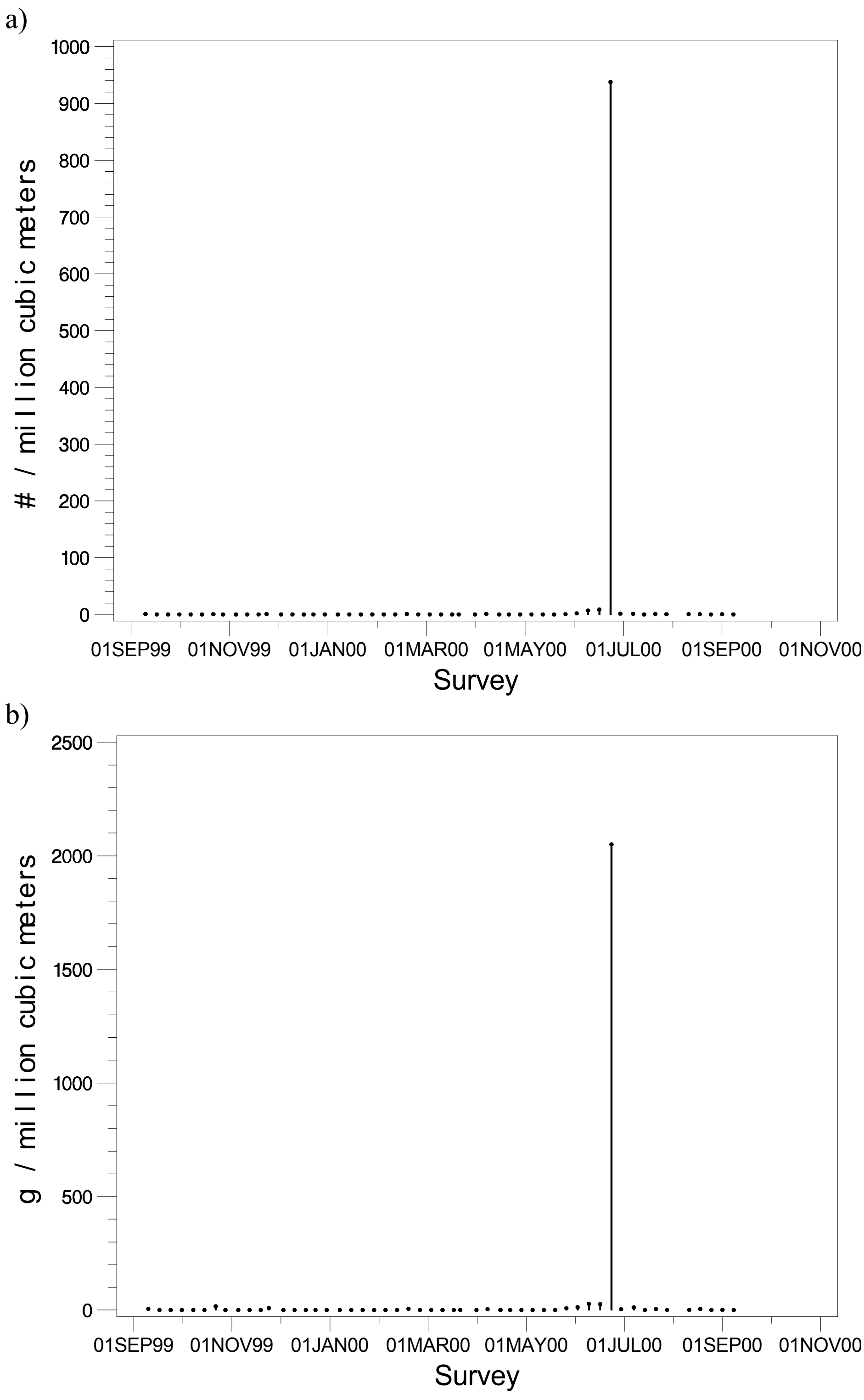


Figure 4-16. Market squid *Loligo opalescens* (n=2,545) impinged at the Morro Bay Power Plant intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6$ m^3) and b) biomass per million m^3 ($g/10^6$ m^3): September 1999 – September 2000.

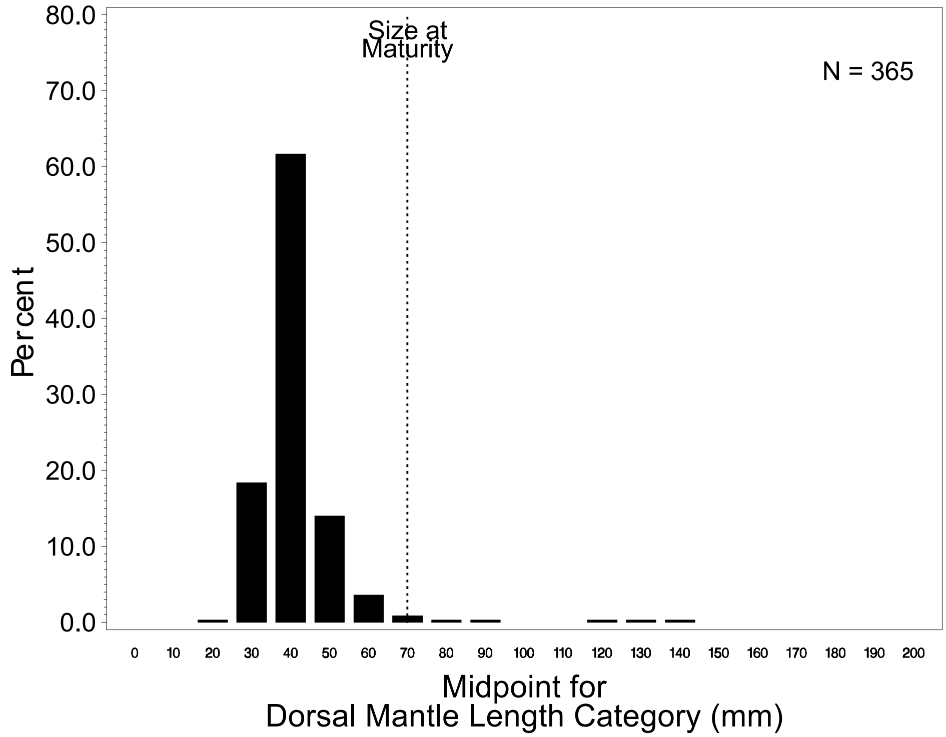
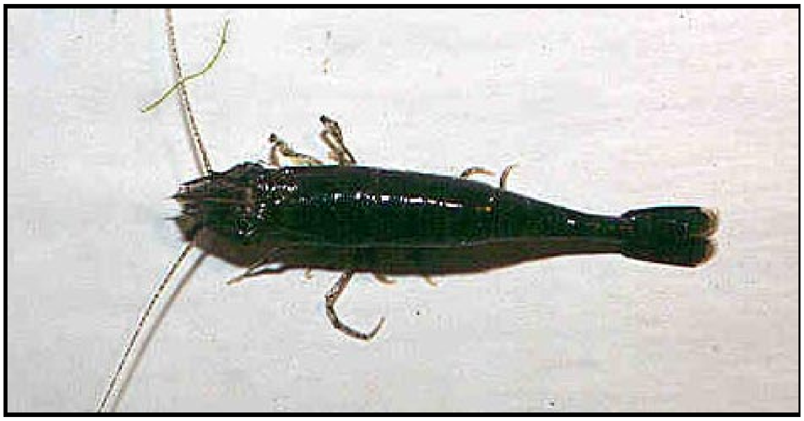


Figure 4-17. Dorsal mantle length (DML) frequency distribution (*n*=365) and DML at first maturity for market squid *Loligo opalescens* impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

DML at first maturity source: Butler et al. 1999, FWIE 1999.

4.5.3.2 Black-tailed Bay Shrimp *Crangon nigricauda*



Photographer: Dan Dugan

Distribution map for black-tailed bay shrimp

Range: From Prince William Sound, Alaska to Isla San Geronimo, Baja California, Mexico.

Life History: Size: to 71 mm (2.8 in.); Size at maturity: females 33 mm (1.3 in.) TL; males 28 mm (1.1 in.) TL; Fecundity: 2,500 to 8,840 eggs; Life span: males about 1.5 years; females 2 to 2.5 years.

Habitat: Sandy bottoms, eelgrass bed. Intertidally to 57 m (187 ft).

Fishery: Commercial bait fishery.

The black-tailed bay shrimp is a member of the family Crangonidae in the order Decapoda. Four representatives of this family commonly occur along the coast of California: *Crangon franciscorum*, *C. nigricauda, C. nigromaculata,* and *C. stylirostris*. *Crangon nigricauda* occurs from Prince William Sound, Alaska to Isla San Geronimo, Baja California, Mexico (Jensen 1995) in the intertidal zone and out to 57 m depth (187 ft) (Morris et al. 1980).

Black-tailed bay shrimp can be up to 71 mm (2.8 in.) long (Jensen 1995), and the size at maturity for females is 33 mm (1.3 in.)and 28 mm (1.1 in.) for males (CDFG http://www.delta.dfg.ca.gov/baydelta/monitoring/cnigri.html). Fecundity is reported to be between 2,500 to 8,840 eggs (NMFS 1989). Male black-tailed bay shrimp live to about 1.5 years, while females live to 2 to 2.5 years (NMFS 1989).

Impingement Results

A total of 1,105 black-tailed bay shrimp weighing approximately 2.1 kg (4.6 lb) was collected during this impingement study at MBPP (Table 4-3). They were most abundant during the late spring and early summer 2000, but a peak was also observed earlier in winter 2000 (Figure 4-18). Impinged biomass of black-tailed bay shrimp generally followed trends in numeric abundance, indicating that most of the shrimp collected were about the same size. Black-tailed bay shrimp impingement for the entire study period was estimated to be approximately 7,500 individuals weighing about 14 kg (31 lb) (Table 4-3).

The majority of the black-tailed shrimp measured in the MBPP impingement study had a narrow size range (Figure 4-19). Carapace lengths ranged from 1 – 90 mm, (0.04 – 3.5 in.) but more than 99 percent of those measured were less than 20 mm (0.8 in.). Gravid females noted on our datasheets yielded a rough field estimate of size at maturity ranging from 3 – 17 mm (0.1 – 0.7 in.) carapace length; a size much smaller than the size at maturity reported in the literature. Thus, the majority of black-tailed shrimp measured at MBPP were assumed to be sexually mature.

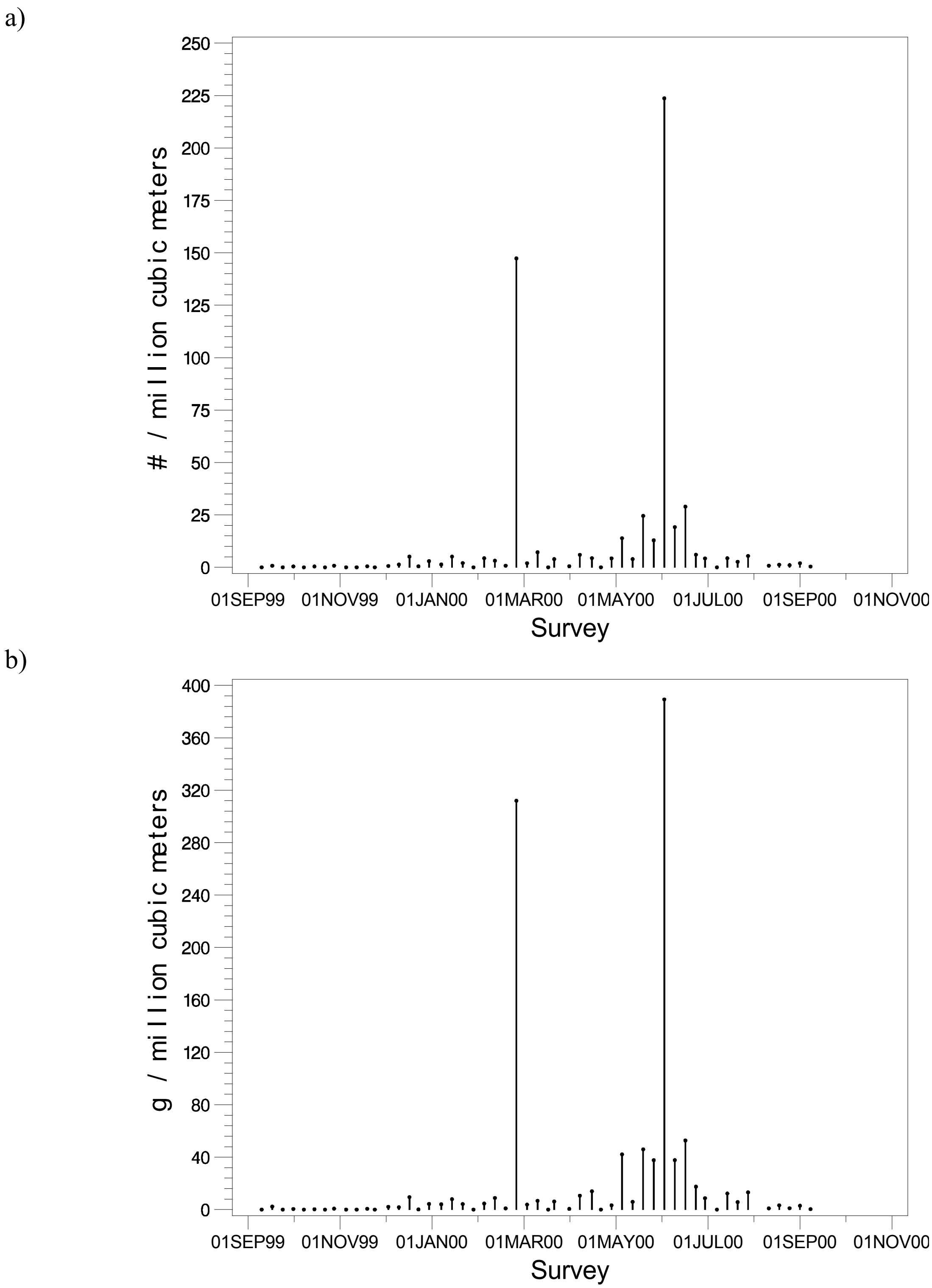


Figure 4-18. Black-tailed bay shrimp *Crangon nigricauda* (*n*=1,105) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 (#/10^6 m^3) and b) biomass per million m^3 (g/10^6 m^3): September 1999 – September 2000.

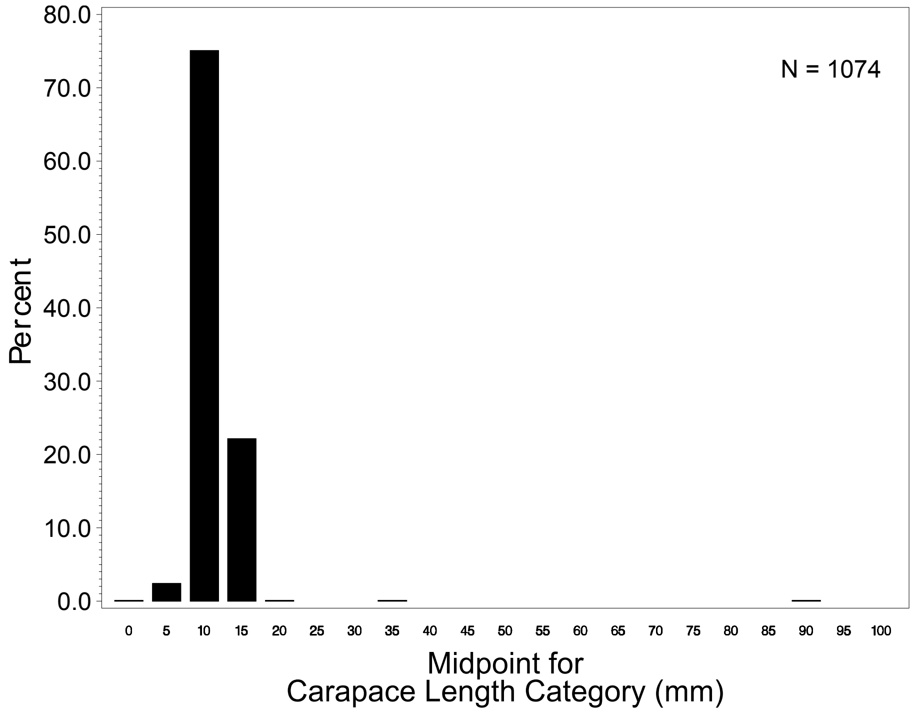
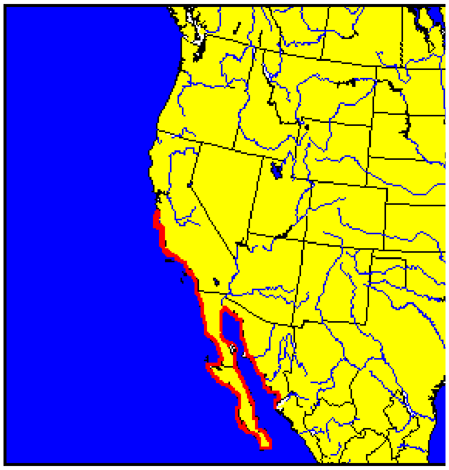


Figure 4-19. Carapace length frequency distribution for black-tailed tailed bay shrimp *Crangon nigricauda* (*n*=1,074) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

4.5.3.3 Xantus' Swimming Crab *Portunus xantusii*

Photographer: Dan Dugan



Distribution map for Xantus' swimming crab

Range: Reported from Santa Barbara, California to Topolobampo, Mexico; occur at least as far north as Moss Landing, California (Tenera, unpubl. data).

Life History: Size: to 73 mm (2.8 in.); Size at maturity: no information available; Fecundity: no information available; Life span: no estimate available.

Habitat: Sand flats, low intertidal zone, in association with eelgrass beds. Subtidally to 179 m (587 ft).

Fishery: No commercial or recreational fishery.

Xantus' swimming crabs occur on sand flats, in the low intertidal zone, and in association with eelgrass beds (Morris et al. 1980). They occur subtidally down to 179 m (591 ft) and are often found swimming on the surface at night. Their range has been reported as Santa Barbara, California to Topolobampo, Mexico (Morris et al. 1980), but they occur at least as far north as Moss Landing, California on Monterey Bay (Tenera Environmental unpubl. data). Males achieve carapace widths of 71 mm (2.8 in.) and females can be 73 mm (2.9 in.); ovigerous female swimming crabs are present May through September (Morris et al. 1980).

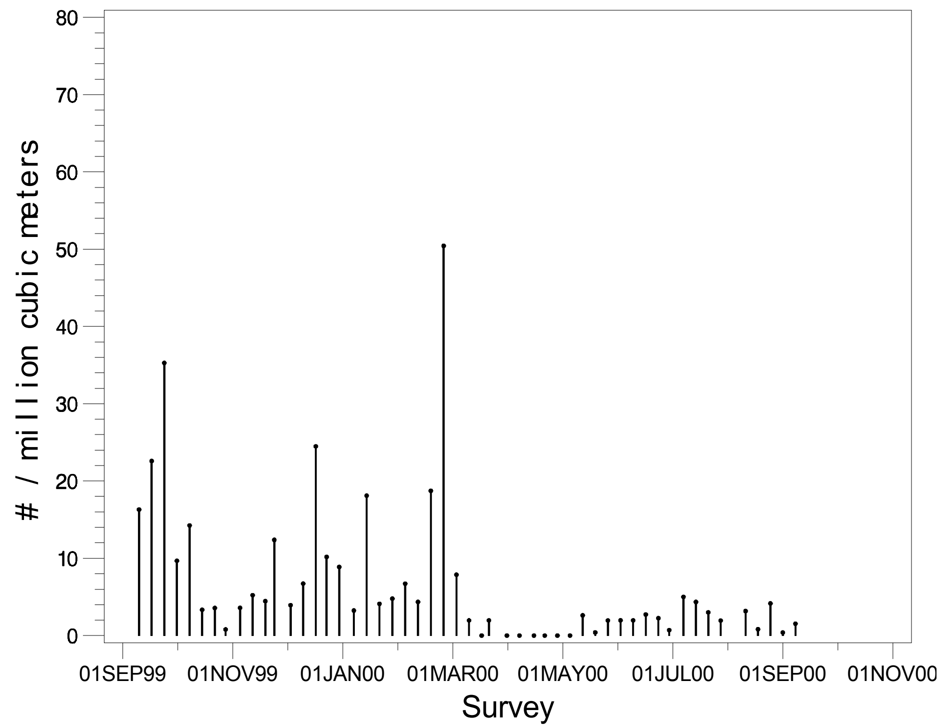
Natural and life history information on Xantus' swimming crab is limited. We found no estimates of fecundity, age or size at maturity, growth rates, or other demographic parameters in the scientific literature.

Impingement Results

A total of 719 Xantus' swimming crabs weighing approximately 13.6 kg (30 lb) was collected during this impingement study at MBPP (Table 4-3). Swimming crabs were most abundant during the first half of the study between September 1999 and February 2000 (Figure 4-20). The majority (68 percent) were collected from the Units 3 and 4 intake. Biomass of swimming crabs followed the trends of numeric abundance. Swimming crab impingement for the entire study period was estimated as approximately 4,800 individuals weighing about 91 kg (200 lb) (Table 4-3).

Xantus' swimming crab carapace widths measured in the impingement studies at MBPP during September 1999 – September 2000 ranged from 22 – 87 mm (0.9 – 6.5 in.) (Figure 4-21). Reported maximum carapace width for this crab has been reported as 73 mm (2.9 in.) for females (Morris et al. 1980). There have been no estimates reported in the literature of size or age at maturity that can be used to compare with the carapace widths measured. However, ovigerous females were noted on the data sheets and yield a rough field estimate of size at maturity of 40 – 50 mm (1.6 – 2.0 in.) carapace width. Based on these observations, the majority of crabs measured at MBPP were potentially sexually mature.

a)



b)

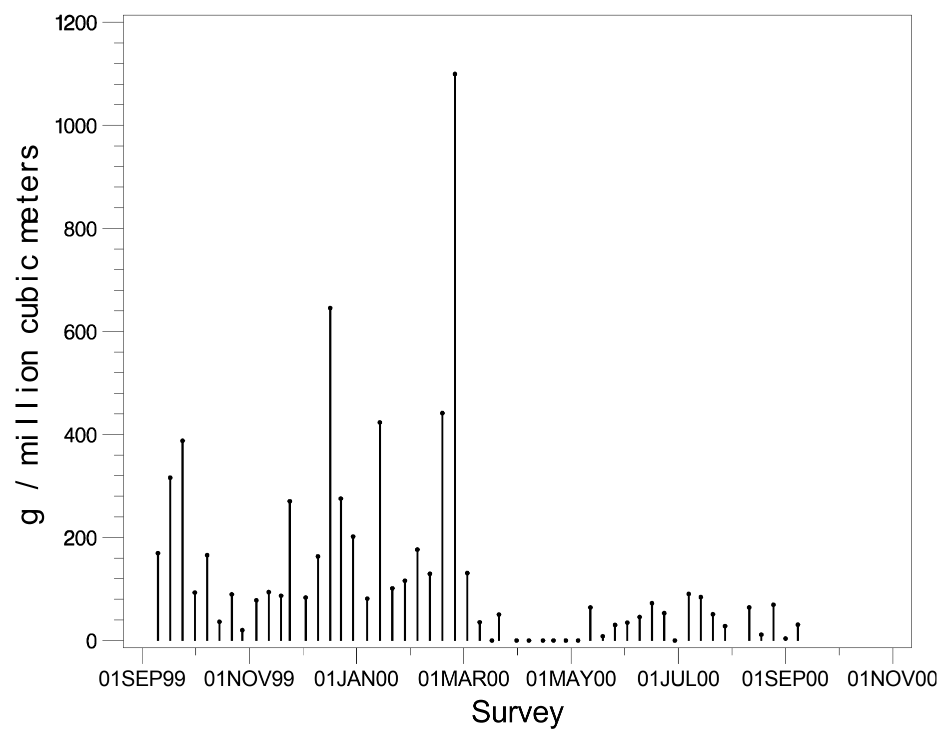


Figure 4-20. Xantus' swimming crab *Portunus xantusii* (*n*=719) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6\ m^3$) and b) biomass per million m^3 ($g/10^6\ m^3$): September 1999 – September 2000.

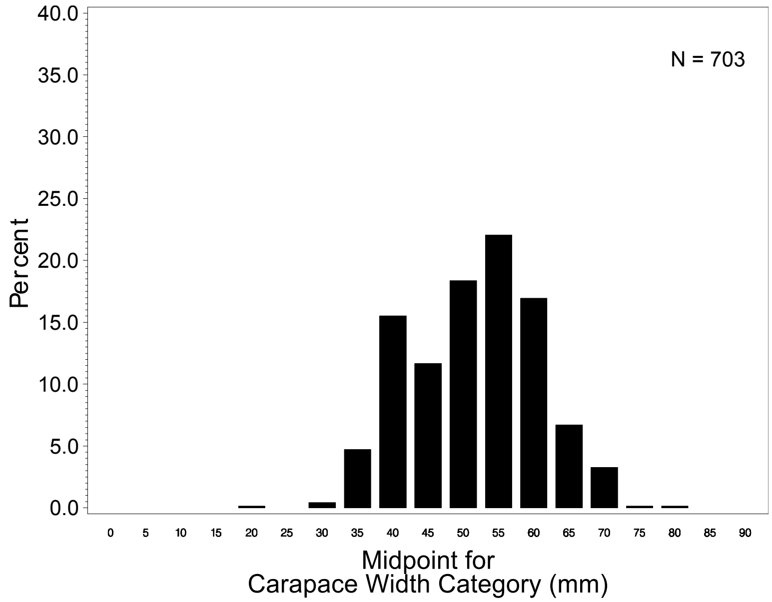
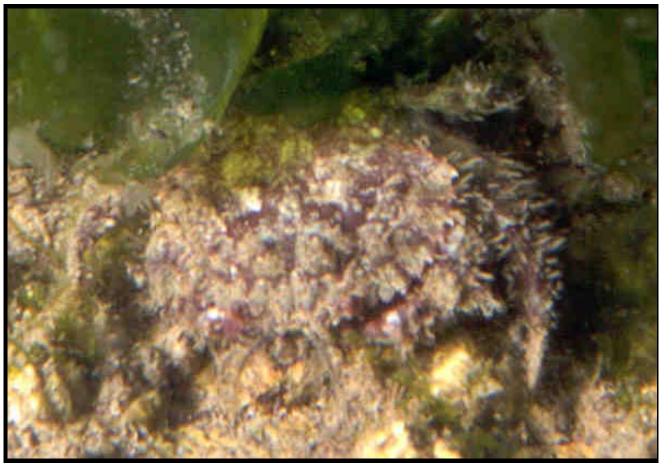
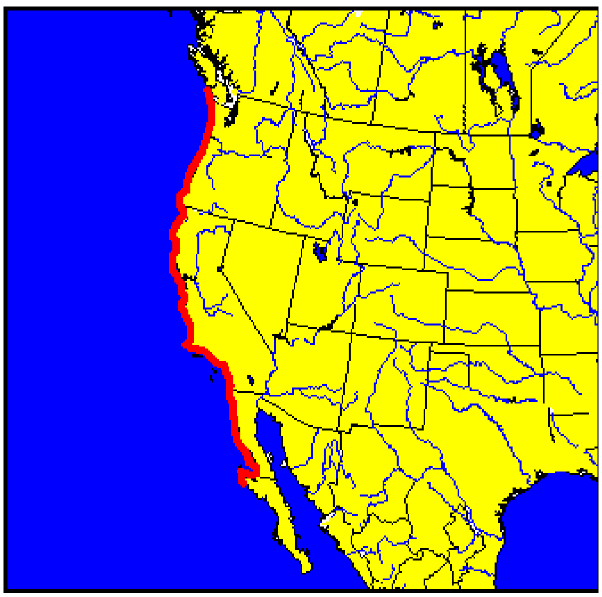


Figure 4-21. Carapace width frequency distribution (*n*=703) for Xantus' swimming crab *Portunus xantusii* impinged at the Morro Bay Power Plant cooling water intakes (Units 1-4 combined): September 1999 – September 2000.

4.5.3.4 Hairy rock crab *Cancer jordani*





Distribution map of 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 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.

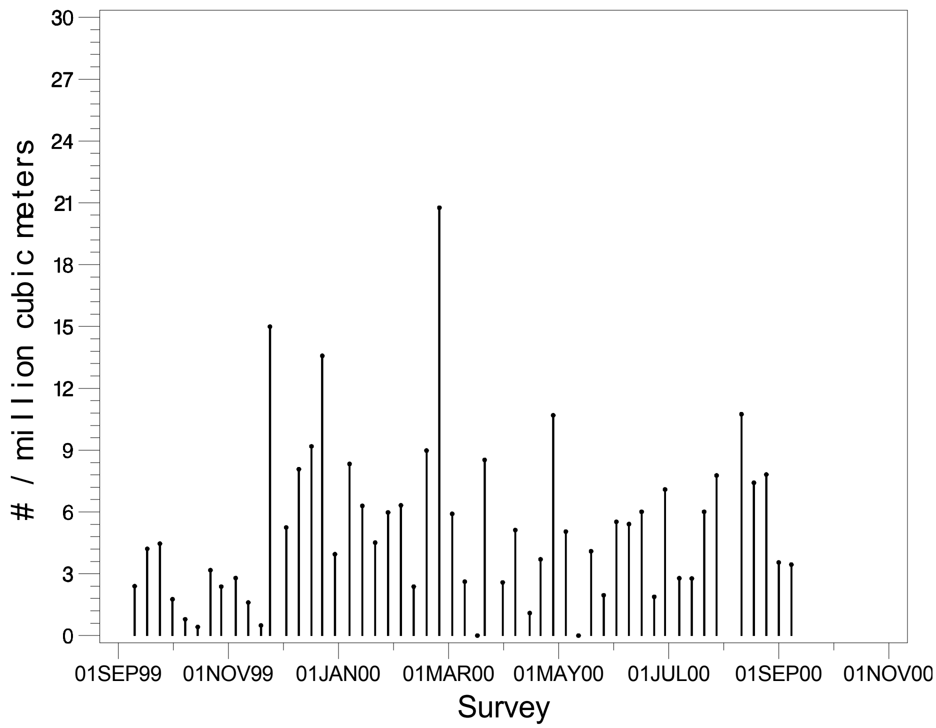
Life history information for hairy rock crab was described in Section 3.3.11.2.

Impingement Results

A total of 544 hairy rock crabs *Cancer jordani* weighing approximately 2 kg (4.4 lb) was collected during the 1999 – 2000 impingement study at MBPP (Table 4-3). They were collected in impingement samples throughout the year, but reached their peak biomass in November and January (Figure 4-22). The majority of hairy rock crabs (68 percent) were collected at the Units 3 and 4 intake. Hairy rock crab impingement for the entire study period was estimated as approximately 3,900 individuals weighing approximately 14 kg (31 lb) (Table 4-3).

The size of impinged hairy rock crabs ranged from 10 – 74 mm (0.4 – 2.9 in.) carapace width (CW) (Figure 4-23). The majority (greater than 50 percent) of specimens measured at MBPP were around 20 mm (0.8 in.) CW. Records of ovigerous females indicate that CW at maturity is around 14 – 21 mm (0.6 – 0.8 in.). Thus, around 80 percent of the hairy rock crab measured in the MBPP impingement study between September 1999 and 2000 were probably sexually mature.

a)



b)

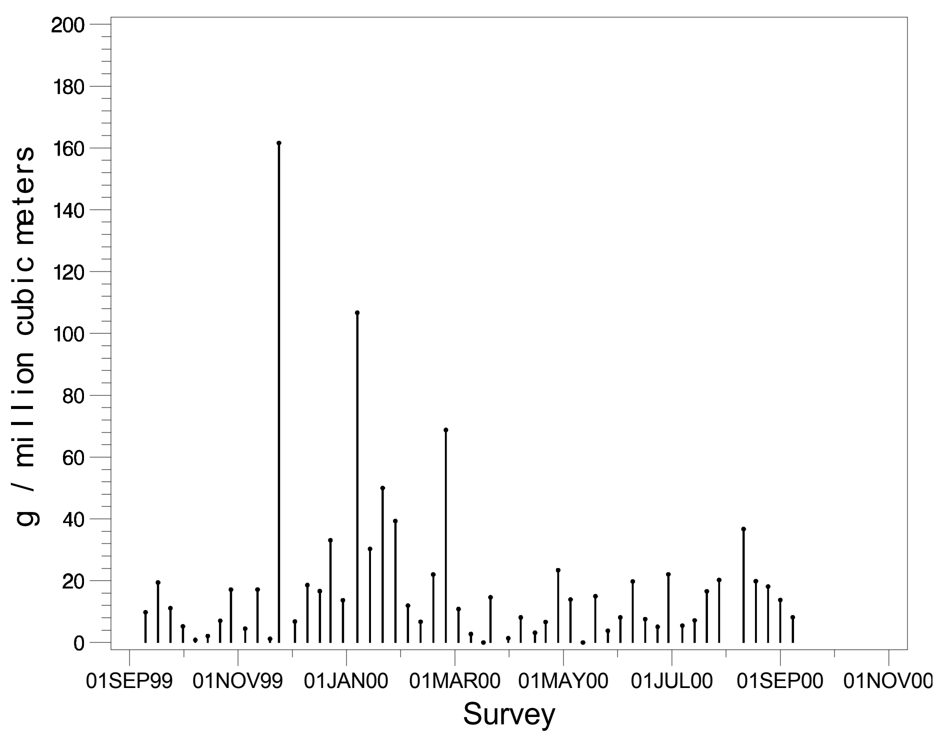


Figure 4-22. Hairy rock crab *Cancer jordani* (*n*=544) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6\ m^3$) and b) biomass per million m^3 ($g/10^6\ m^3$): September 1999 – September 2000.

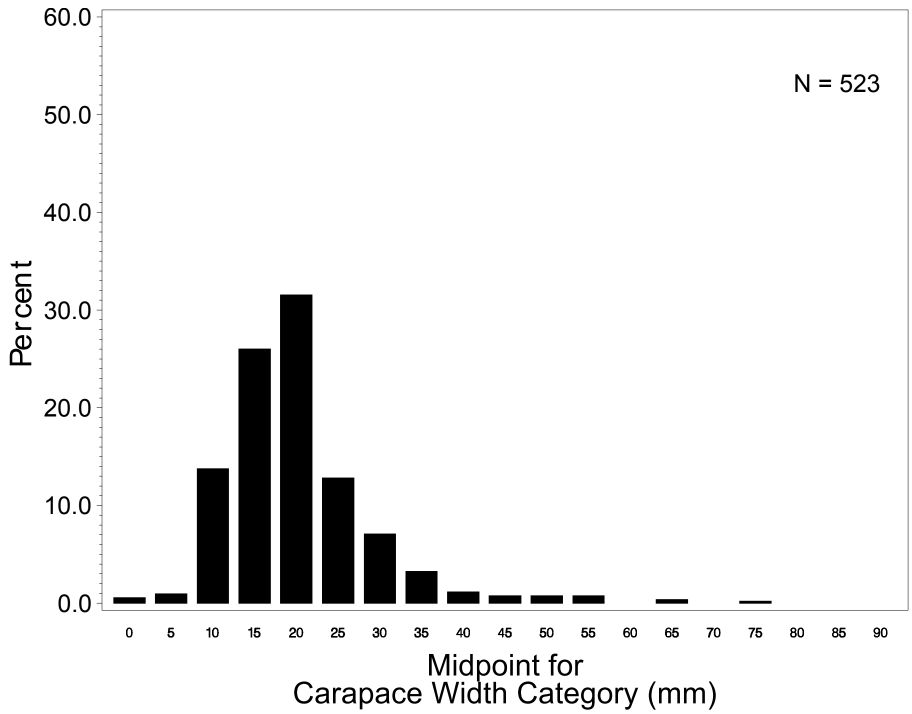
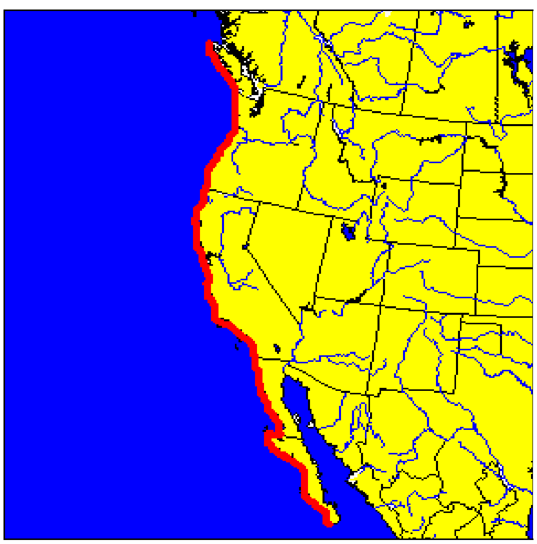


Figure 4-23. Carapace width frequency distribution (*n*=523) for hairy rock crab *Cancer jordani* impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

4.5.3.5 Brown rock crab Cancer antennarius

Photographer: Dan Dugan



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.

Life history information for brown rock crab was described in Section 3.3.11.1.

Impingement Results

A total of 503 brown rock crabs weighing approximately 11 kg (24 lb) was collected during impingement sampling (Table 4-3). Brown rock crabs reached their highest abundances in June/July (Figure 4-24). Impingement biomass for brown rock crabs showed two distinct peaks during the study period; one peak occurring in September/October 1999 and another occurring in July 2000 when abundances were highest. Brown rock crab impingement for the entire study period was estimated as approximately 3,900 individuals weighing about 82 kg (181 lb) (Table 4-3).

The length frequency distribution for impinged brown rock crabs ranged from approximately 8 – 144 mm (0.3 – 5.7 in.) CW (Figure 4-25). The majority of impinged brown rock crabs were smaller than their reported size at maturity (between 60 – 80 mm [2 – 3 in.] CW) (Carroll 1982).

a)

b)

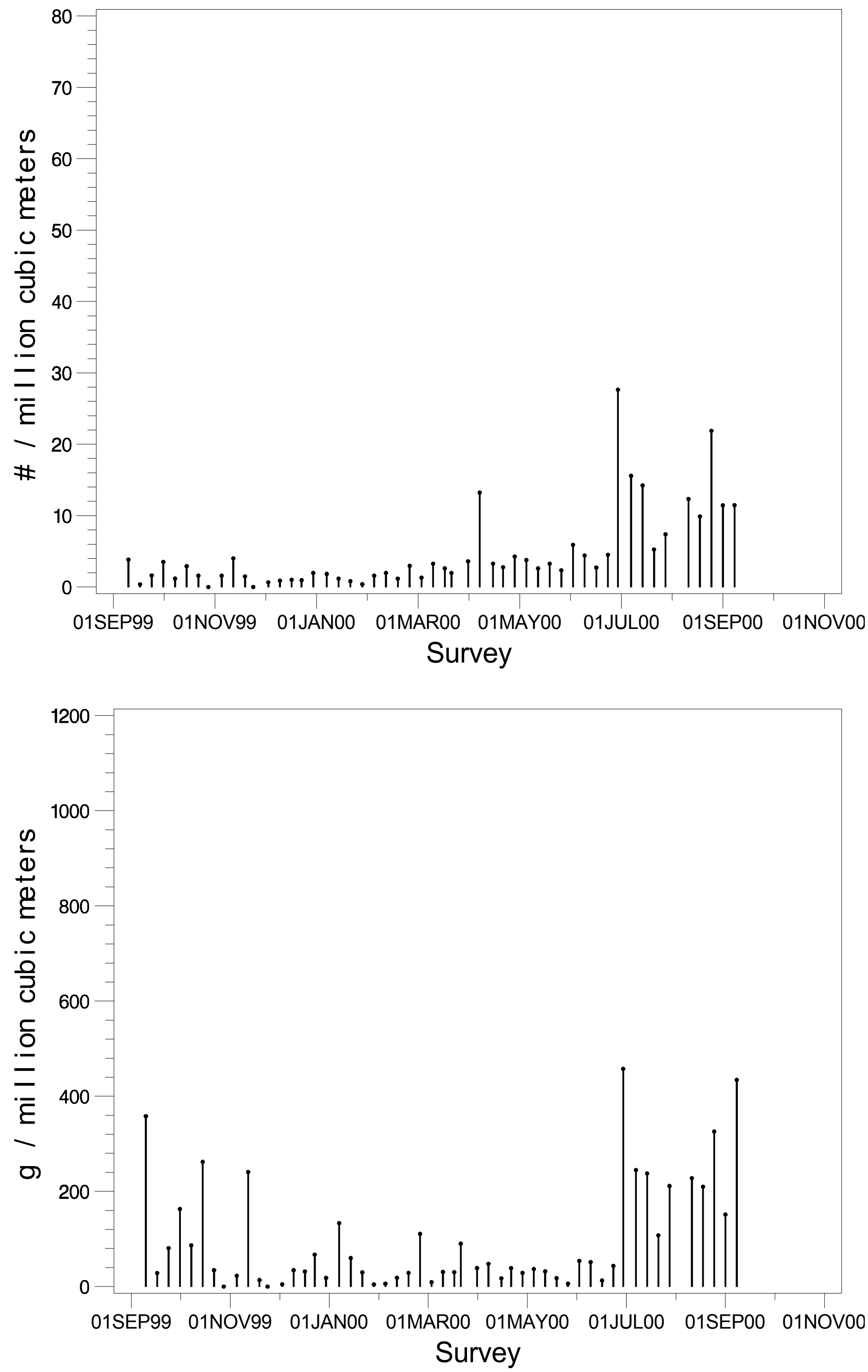


Figure 4-24. Brown rock crab *Cancer antennarius* (n=503) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6$ m^3) and b) biomass per million m^3 ($g/10^6$ m^3): September 1999 – September 2000.

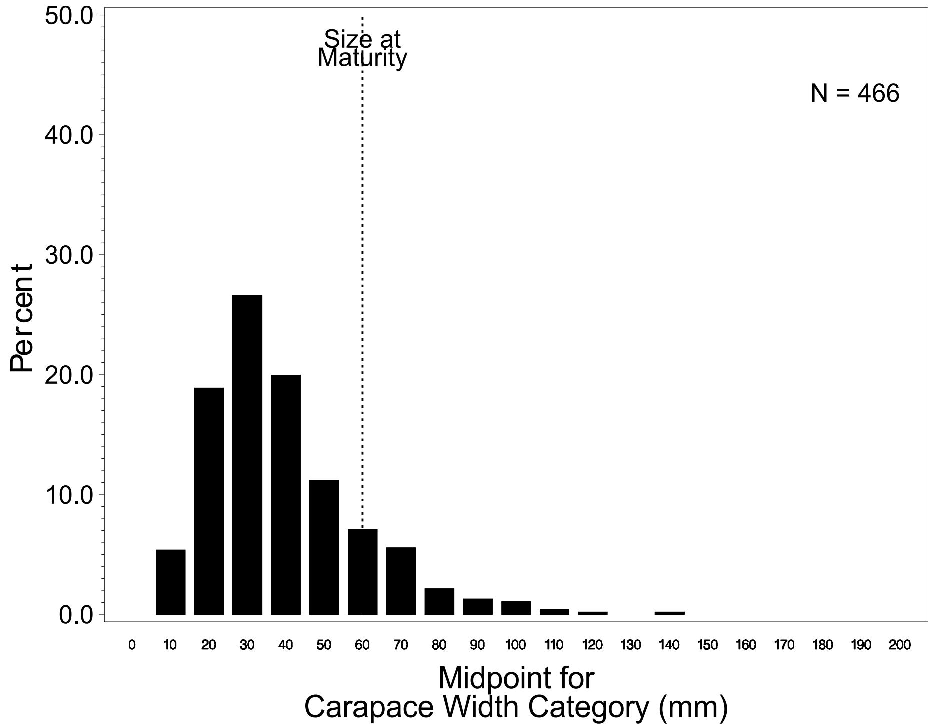
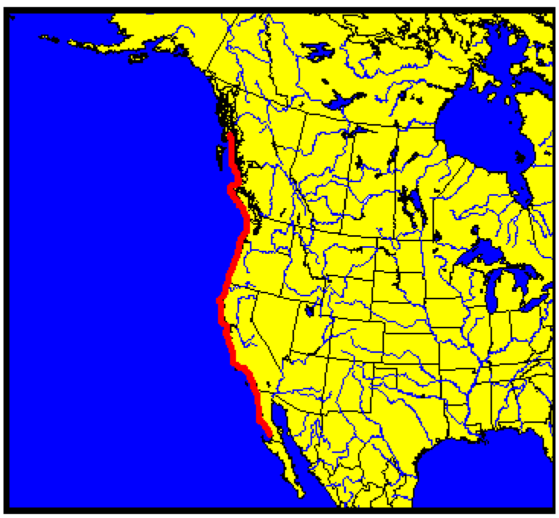


Figure 4-25. Carapace width frequency distribution (*n*=466) for brown rock crab *Cancer antennarius* impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

4.5.3.6 Northern Kelp Crab *Pugettia producta*

Photographer: Dan Dugan



Distribution map for northern kelp crab

Range: From Prince of Wales Island, Alaska to Baja California.

Life History: Males to 93 mm (3.6 in.); females to 78 mm (3 in.); Size at maturity: females as small as 26 mm (1 in.) carapace width; Fecundity: 34,000 to 84,000 eggs; Life span: no estimate available.

Habitat: Adults found in kelp canopy and are common on wharf pilings; juveniles found intertidally among algae and under rock. Found at depths to 73 m (240 ft).

Fishery: No commercial or recreational fishery

Juvenile northern kelp crabs are common among rocks or on the brown alga *Egregia*. They are found at low intertidal elevations on rocky shores of protected outer coasts in winter, but migrate to floating kelp (*Macrocystis* and *Nereocystis*) with age. They are found subtidally from the low intertidal zone to depths of 73 m (239 ft) from Prince of Wales Island, Alaska to Baja California (Morris et al. 1980).

Breeding occurs year-round in California. Females mate in hard-shelled form and nearly 50 percent of females are found carrying eggs at all times of the year. The smallest sexually mature females have a carapace width of approximately 26 mm (1 in.) (Garth 1958). Fecundity for 41 – 55 mm (1.6 – 2 .2 in.) carapace width females averages 61,000 in Puget Sound (range = 34,000 – 84,000). Incubation times appear to be around 28 – 31 days in

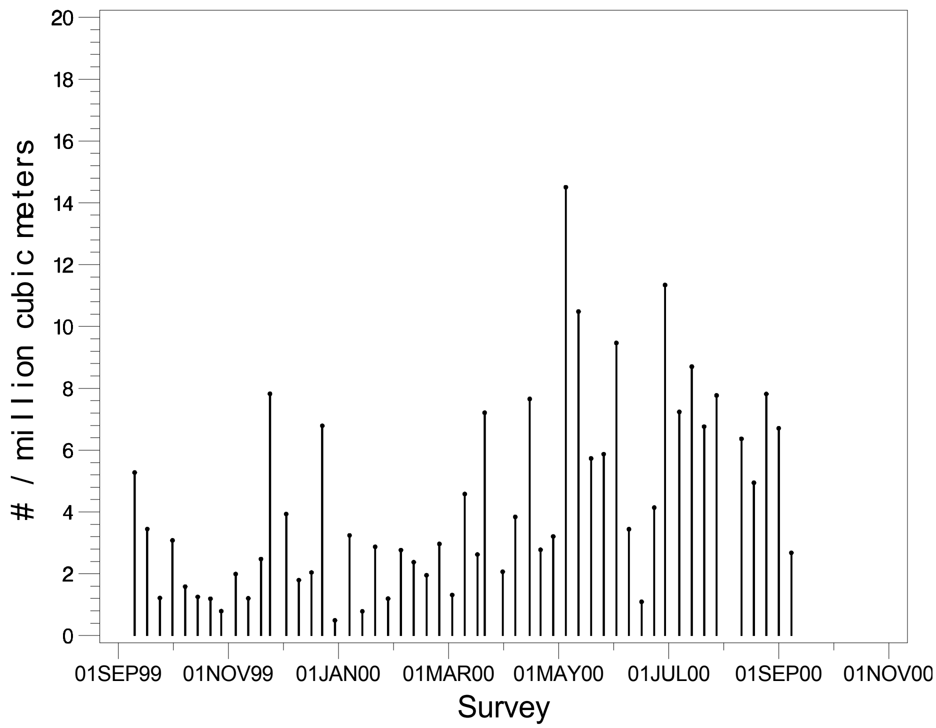
Monterey Bay and females in the laboratory have been capable of producing a new batch of offspring every 30 days (Boolootian et al. 1959, Morris et al. 1980).

Impingement Results

A total of 445 northern kelp crabs weighing approximately 3.8 kg (8.3 lb) was collected during impingement surveys at MBPP (Table 4-3). Northern kelp crabs were collected throughout the year, but appeared to reach peak abundance in the late spring and summer months (Figure 4-26). The majority (78 percent) were collected from the Units 3 and 4 intake. The occurrence of a few large individuals on several occasions during the course of the survey was apparent from spikes in biomass paired with relatively low numbers of kelp crabs impinged. The northern kelp crab impingement for the entire study period was estimated to be approximately 3,200 individuals weighing nearly 28 kg (62 lb) (Table 4-3).

Northern kelp crabs measured in the MBPP impingement study between September 1999 and September 2000 ranged from 4 – 72 mm (0.2 – 2.8 in.) CW (Figure 4-27). The reported carapace width at first maturity for females is 26 mm (1.0 in.) (Garth 1958). Therefore, around 20 percent of the kelp crabs measured in this study were probably sexually mature.

a)



b)

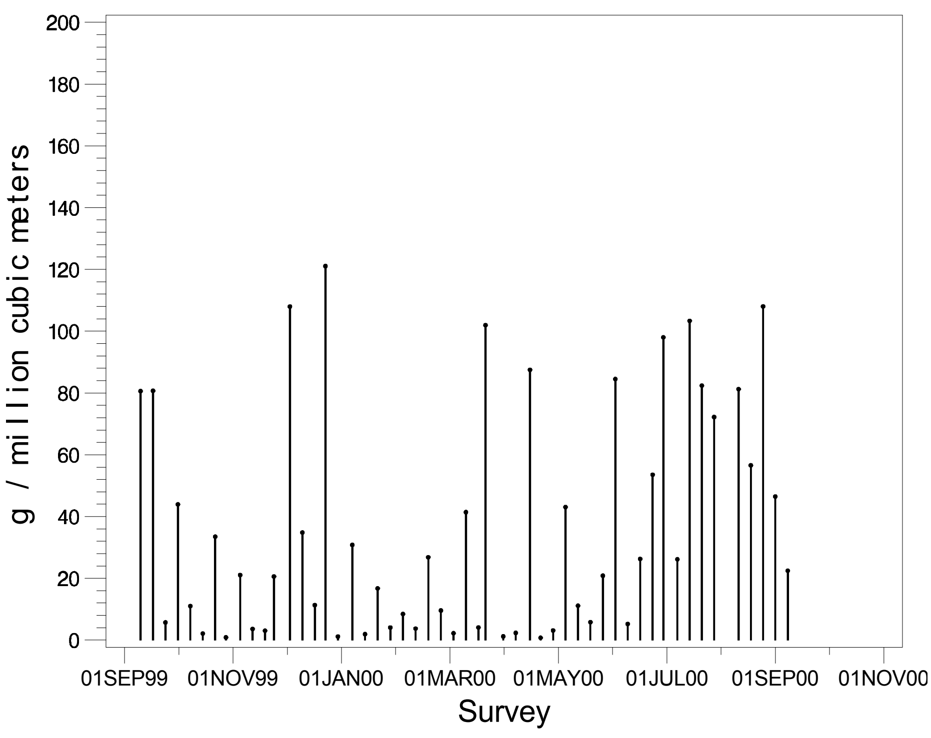


Figure 4-26. Northern kelp crabs *Pugettia producta* (*n*=443) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6$ m^3) and b) biomass per million m^3 ($g/10^6$ m^3): September 1999 – September 2000.

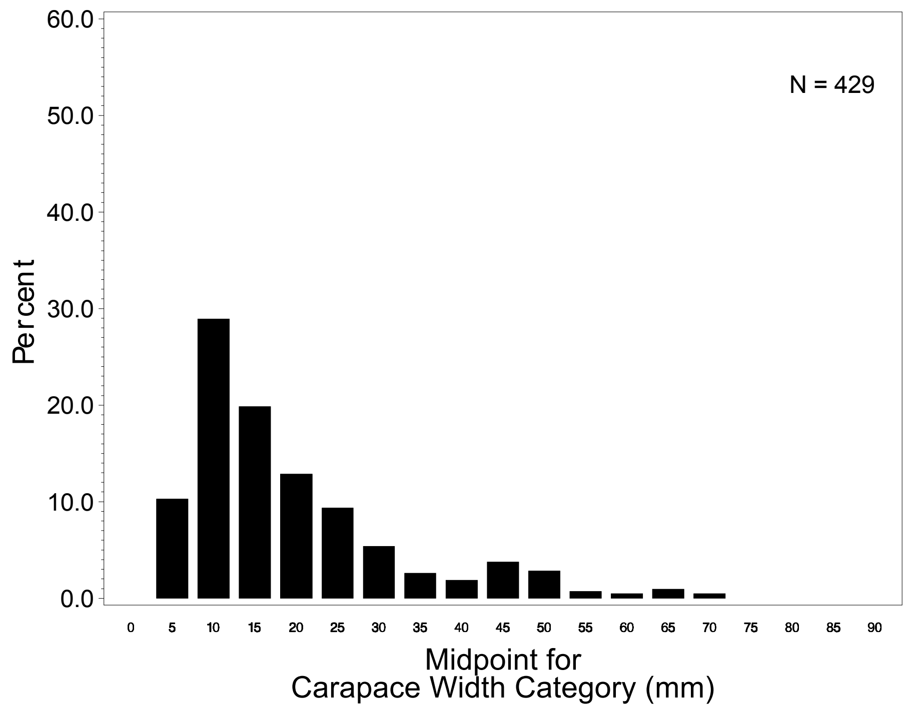
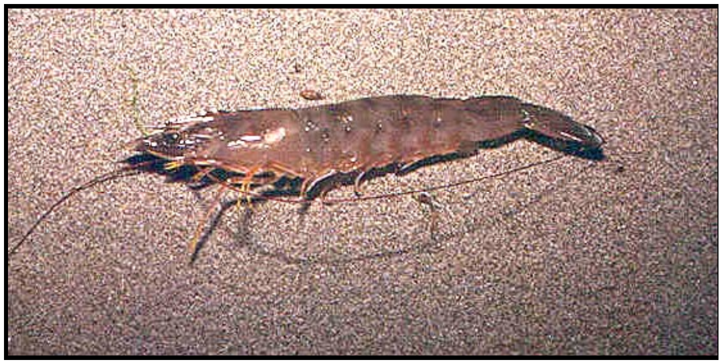
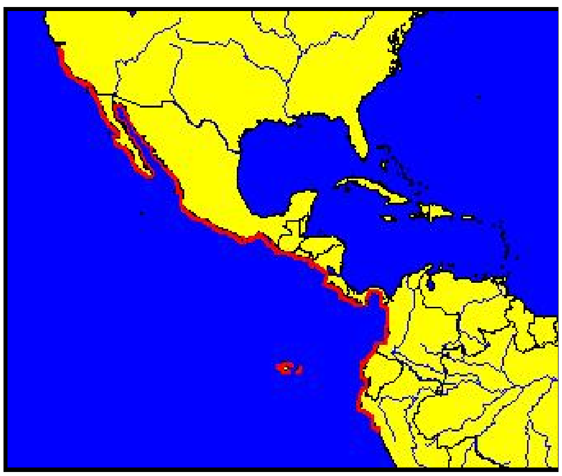


Figure 4-27. Carapace width frequency distribution (*n*=429) for kelp crab *Pugettia producta* impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

4.5.3.7 Brown Shrimp *Penaeus californiensis*



Photographer: Dan Dugan



Distribution map for brown shrimp

Range: From San Francisco Bay, California to Callao, Peru and the Galapagos.

Life History: Size: to 250 mm (9.8 in.) total length; Fecundity: no specific information available; Life span: no estimate available.

Habitat: Over mud or sand bottoms in depths from 3 to 100 m (10 to 330 ft).

Fishery: Commercially in Mexico; incidentally taken in California.

The brown shrimp is found over mud or sand bottoms in depths from 3 – 100 m (10 – 330 ft) from San Francisco Bay, California to Callao, Peru and the Galapagos (Jensen 1995). This species is important commercially in Mexico and it is often taken in California fisheries as well; typically as incidental catch and not as a targeted species. The Penaeoidea as a group are unique among the decapods since they are the only members to freely spawn their eggs rather than brooding them.

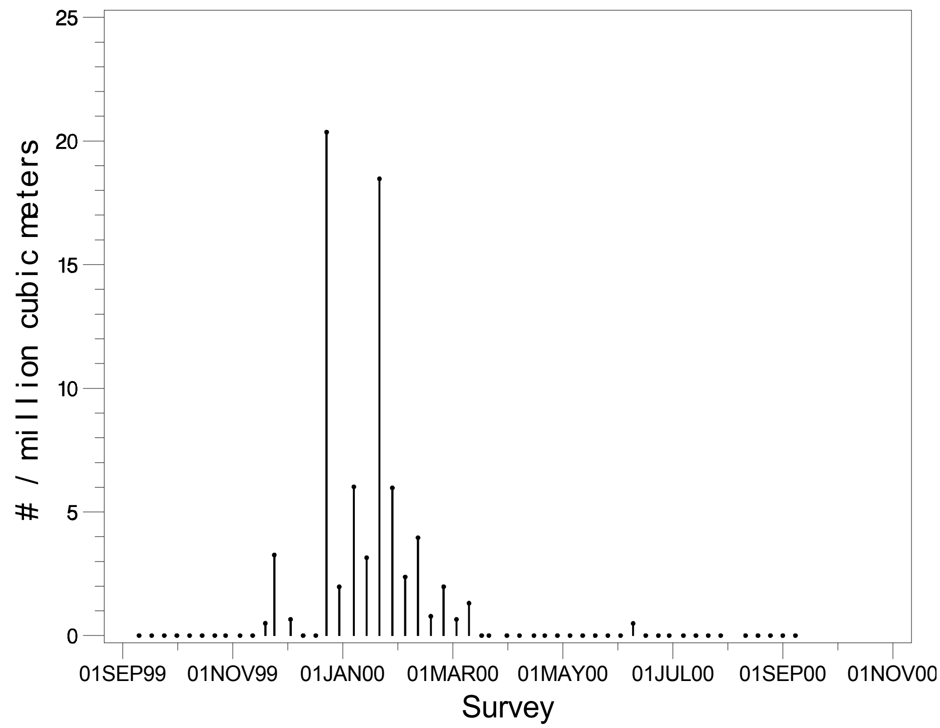
Little demographic information has been found in the literature for this species. None of the specimens collected at MBPP were gravid so field estimates of length at maturity were not derived from our data.

Impingement Results

A total of 158 brown shrimp weighing approximately 4.8 kg (10.6 lb) was collected during the impingement study at MBPP (Table 4-3). They were most abundant within a two-month period between December 1999 and February 2000 (Figure 4-28). The majority of brown shrimp were collected at the Units 3 and 4 intake. Brown shrimp impingement for the entire study period was estimated to be approximately 1,000 individuals weighing nearly 31 kg (68 lb) (Table 4-3).

Brown shrimp measured in the MBPP impingement study (September 1999 – September 2000) ranged from 30 – 207 mm (1.2 – 8.2 in.) carapace length (Figure 4-29). There were no reported estimates of carapace length at sexual maturity in the literature for this species. Therefore, it is unknown what proportion of the brown shrimp impinged were sexually mature.

a)



b)

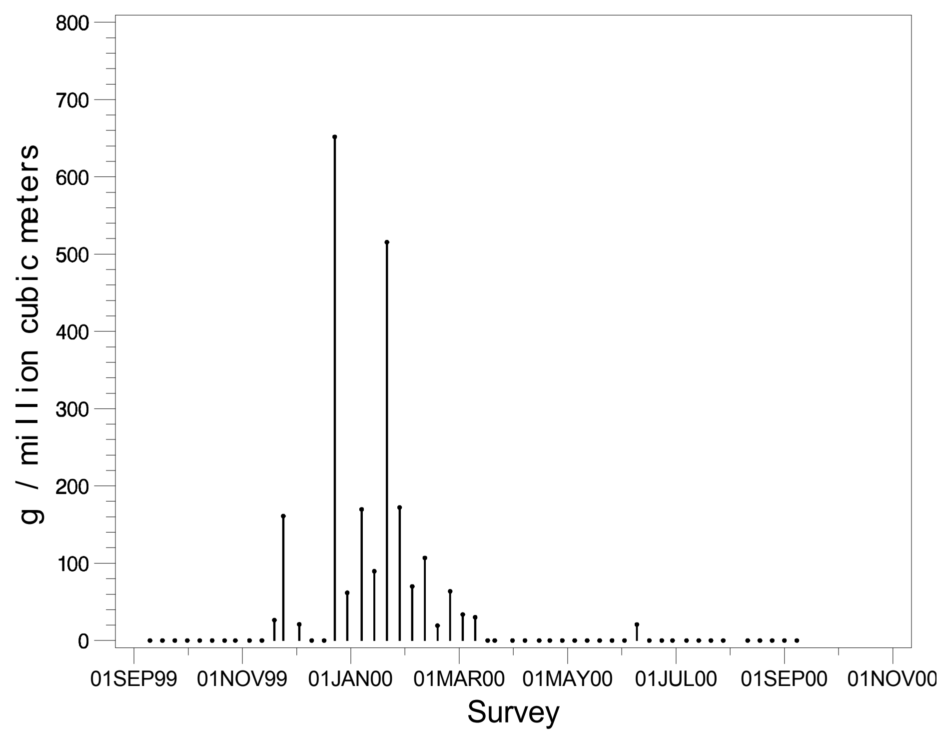


Figure 4-28. Brown shrimp *Penaeus californiensis* (*n*=158) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6$ m^3) and b) biomass per million m^3 ($g/10^6$ m^3): September 1999 – September 2000.

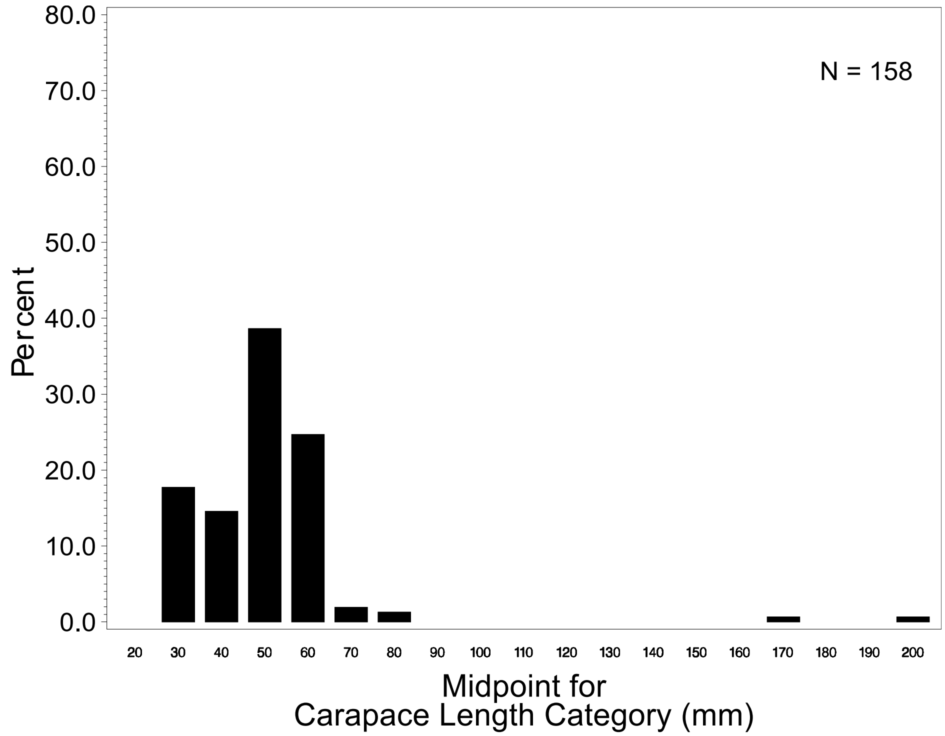
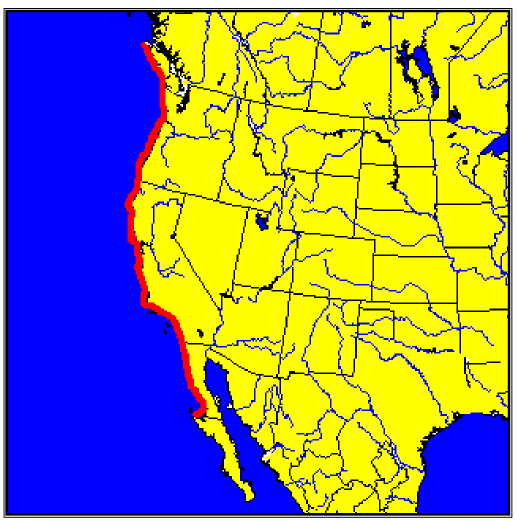


Figure 4-29. Carapace width frequency distribution (*n*=158) for brown shrimp *Penaeus californiensis* impinged at the Morro Bay Power Plant cooling water intakes (Units 1-4 combined): September 1999 – September 2000.

4.5.3.8 Purple Sea Urchin *Strongylocentrotus purpuratus*

Photographer: Dan Dugan



Distribution map for purple sea urchin

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

Life History: Size: test to 89 mm (3.5 in.); Size at maturity: 25 mm (1.0 in.); Fecundity: no specific information available; Life span: 10 to 30 years of age.

Habitat: Moderately high wave exposed habitats from the shallow subtidal to 160 m (525 ft).

Fishery: No commercial or recreational fishery.

Purple sea urchins *Strongylocentrotus purpuratus* are common in lower intertidal elevations on rocky shores in the absence of sea otters. They are typically found in moderately high wave exposed habitats from the shallow subtidal to 160 m (525 ft) (Morris et al. 1980). Their range extends from Vancouver Island, British Columbia to Isla Cedros, Baja California.

Purple sea urchins become sexually mature at two years of age and 25 mm (1.0 in.) or more in test diameter (Morris et al. 1980). Virtually all purple urchins are reproductively active by

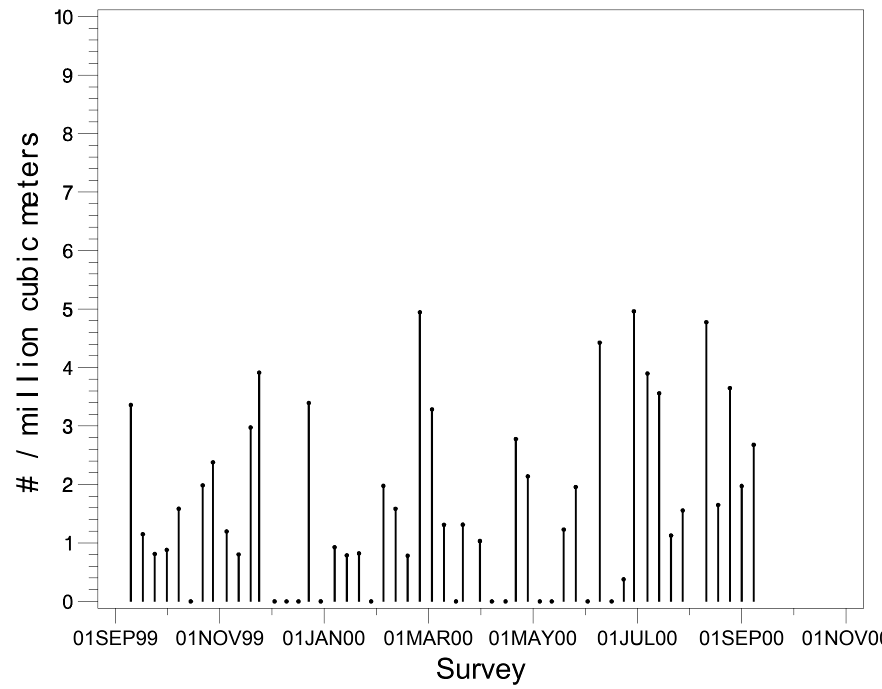
40 mm (1.6 in.) test diameter (Gonor 1972). Spawning occurs in the winter throughout much of their range, but can and does occur year-round with fertilization occurring in the water column (Lasker and Giese 1954, Gonor 1973). The sexes are separate, but occasionally hermaphroditic specimens have been found. Juvenile growth (following metamorphosis) is slow. The largest individuals can be 10 – 30 years of age, but size alone is not a reliable indicator of age.

Impingement Results

A total of 171 purple sea urchins weighing approximately 1 kg (2.3 lb) was collected during the 1999 – 2000 impingement study at MBPP (Table 4-3). They were present throughout the year, but reached their peak impinged biomass during July 2000 (Figure 4-30). Purple sea urchin impingement for the entire study period was estimated to be approximately 1,2750 individuals weighing about 7.6 kg (16.7 lb) (Table 4-3).

Purple sea urchins measured in the MBPP impingement studies from September 1999 – September 2000 ranged from 5 – 57 mm (0.2 – 2.2 in.) test diameter (Figure 4-31). Their reported size at maturity is 25 mm (1.0 in.) (Gonor 1972, Morris et al. 1980). Based on this estimate, the majority of impinged purple sea urchins were immature.

a)



b)

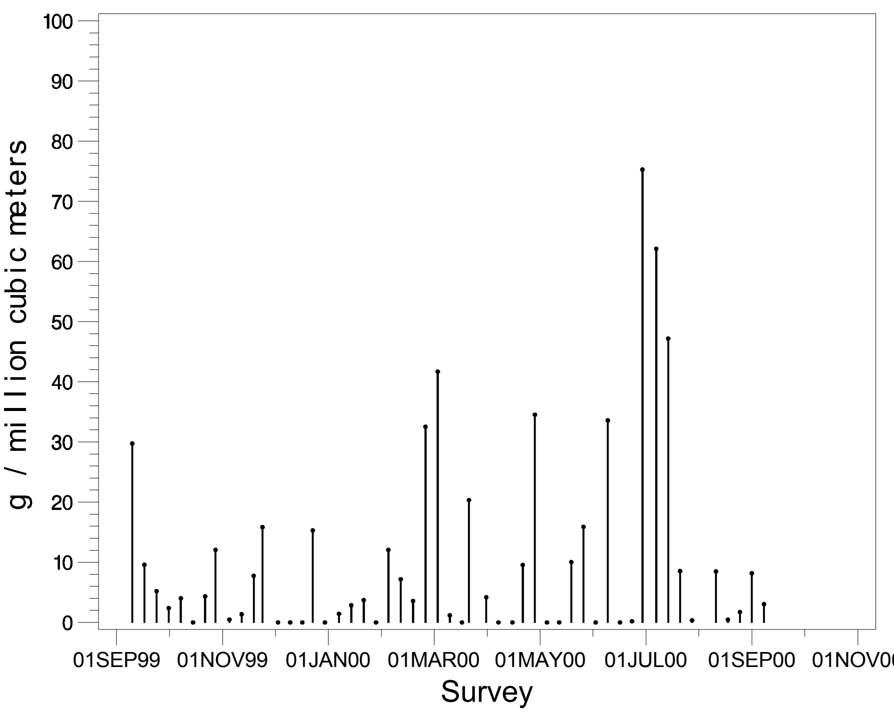


Figure 4-30. Purple sea urchin *Strongylocentrotus purpuratus* (n=171) impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined) standardized by cooling water intake flow in units of a) individuals per million m^3 ($\#/10^6\ m^3$) and b) biomass per million m^3 ($g/10^6\ m^3$): September 1999 – September 2000.

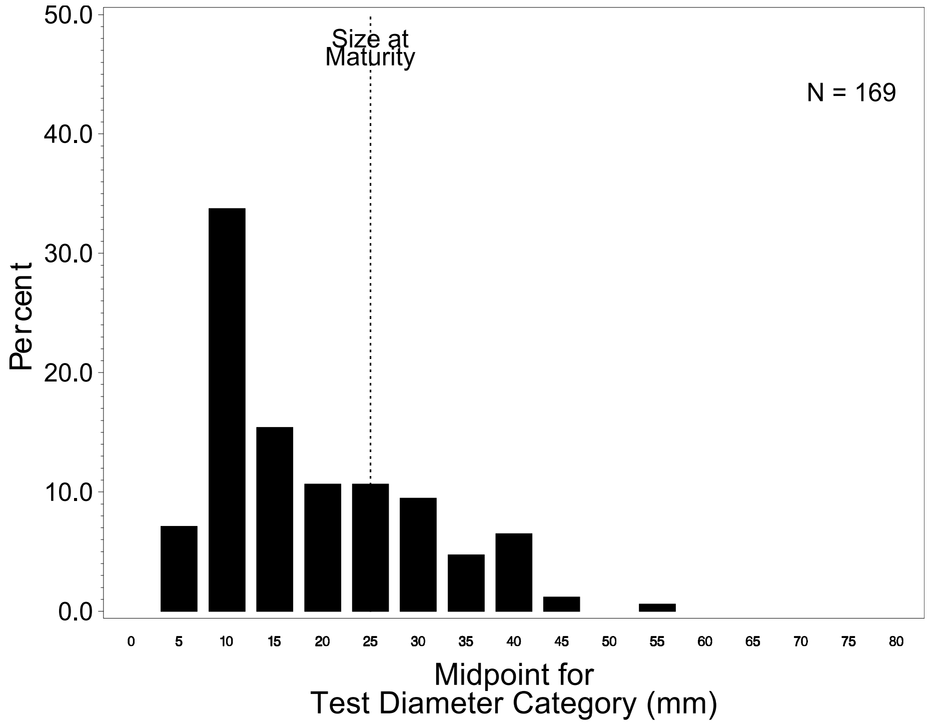


Figure 4-31. Test diameter frequency distribution (*n*=169) for purple sea urchin *Strongylocentrotus purpuratus* impinged at the Morro Bay Power Plant cooling water intakes (Units 1–4 combined): September 1999 – September 2000.

4.6 Factors Affecting Impingement

A number of environmental (e.g., season, water temperature, tides) and operational factors can influence the composition and abundance of the organisms that are subject to impingement. Other factors such as tidal displacement and phase as well as debris can have a more direct effect on impingement rates by altering flow patterns around the intake structures. Heavy debris loads or large influxes of invertebrates (e.g., small jellyfish) or increased flow past the intakes during tidal exchanges may reduce the ability of an organism to avoid impingement. For example, large quantities of eelgrass or algae impinged on the traveling screens can entangle organisms, thus hindering escape. Other physical factors related to plant operation such as circulating water pump operation and screen wash frequency have also been shown to have a direct effect on impingement (Behrens and Sommerville 1982).

Power plant operational characteristics had the greatest effect on impingement rates. The cooling water intake flow during each impingement survey for each set of units was calculated by multiplying the minutes within each collection cycle by the intake flow rate (m^3/min or gal/min) weighted by the number of pumps operating during the cycle. At certain times of the year, rates of cooling water flow had a large influence over impingement. Seasonal composition and abundance of fauna in the vicinity of the MBPP CWIS determine whether increased flow rates will result in increased impingement.

Debris volume roughly paralleled flow rates in both units at MBPP (Figure 4-32), although seasonal variations appear to interfere with this pattern. In most cases, higher flow rates resulted in higher debris loads. Units 3 and 4 had a greater flow rate and were operated more consistently than Units 1 and 2 during the study period. Debris volume was also greater at Units 3 and 4. Debris volumes were greatest during June, but otherwise showed no apparent seasonal trends. These results contrast with those of the previous study that showed a clear seasonal trend that peaked in October (see Figure 26 in Behrens and Sommerville 1982). The fall peak in the previous study coincided with the deterioration of seagrasses and other marine plants after the spring and summer periods of maximum growth.

Large debris loads were linked to increased impingement rates in the previous impingement study at MBPP (Behrens and Sommerville 1982). However, data from this study did not support similar conclusions. Abundance of impinged fishes and invertebrates did not demonstrate a relationship with impinged debris volume (Figure 4-33).

Data from individual cycles within each survey were used to investigate what other factors might be important in determining impingement rates. The data from each set of units were analyzed separately using a multiple regression model. Variables for light regime (i.e., day/night), tide, and tidal flow were created for the multiple regression analyses. Diel light regimes were determined based on the start time of the screen wash for the cycle. Tidal condition during the cycles were designated as either high tide (tidal heights greater than 1.1 m [3.5 ft], low tide (tidal heights less than .46 m [1.5 ft], or midwater tide (tides between high and low tides). Tidal flow based on the tidal differential between cycles was also included in the model. A large negative tidal differential was designated as an ebbing tide, a large positive differential was designated as a flood tide and other tidal differentials were designated as slack tides. The month in which the survey was conducted was also included in the analyses.

The results of the multiple regression analyses showed that variables other than debris alone were potentially better predictors of impingement (Table 4-5). The results showed that variables for month of collection and diel light regime were the best predictors of impingement at both intakes. Time of year was the most important factor in predicting impingement rates (Table 4-5, Figure 4-34). Individual means and confidence intervals for the different variables used in the model at the two intakes showed the influence of day versus night collections; at Units 3 and 4 the average impingement rate during the nighttime was over three times the rate during the day (Table 4-6). Average impingement rates under different tidal flows showed large differences, but there was also large variation associated with tidal flow. While differences in diel impingement rates may have occurred during the year, large tidal differentials were less frequent and varied seasonally.

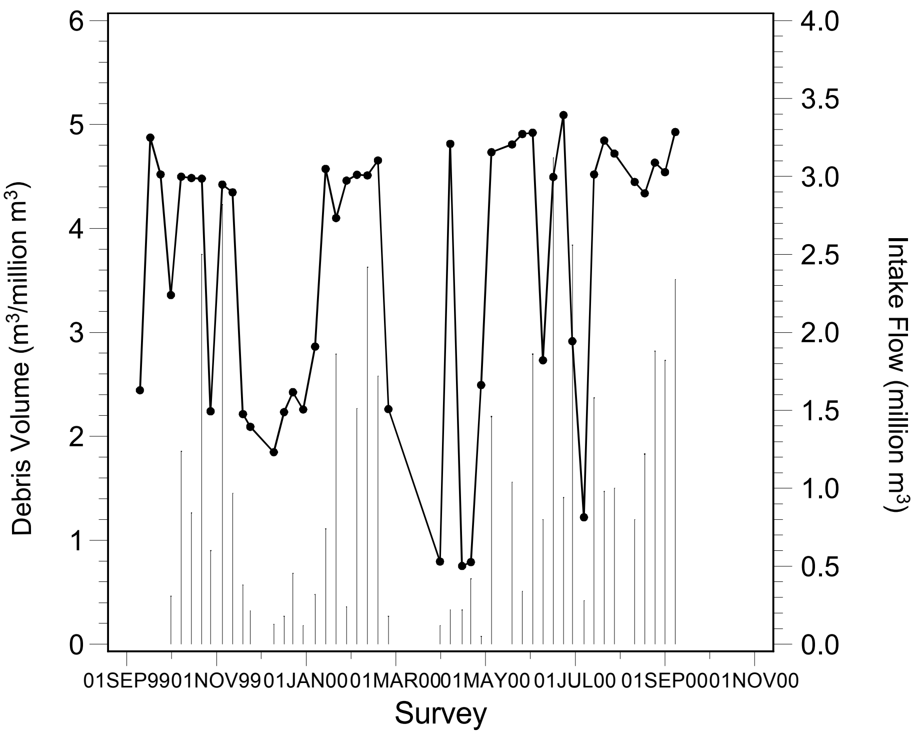
Table 4-5. Results of multiple regression analysis of Log_{10}(Impingement Rate +1). Impingement rate was computed as # of organisms per million m^3. Probability and R^2 for the regression models from each set of units are presented in the row for the unit. F-values significant at an alpha level of 0.05 are shown in bold type.

Source	Degrees of Freedom	Sums of Squares	Mean Square	F-Value	Probability
Units 1 and 2 (p=<0.0001, R^2=0.4172)					
Log (Debris Rate)	1	0.1313	0.1313	0.48	0.4911
Month	11	26.9309	2.4483	8.87	**<.0001**
Tide (High, Medium, Low)	2	1.3192	0.6596	2.39	0.0941
Tidal Flow (Ebb, Flood, Slack)	2	0.3951	0.1975	0.72	0.4900
Day-Night	1	7.0611	7.0611	25.58	**<.0001**
Units 3 and 4 (p=<0.0001, R^2=0.4130)					
Log (Debris Rate)	1	1.2263	1.2263	8.01	**0.0050**
Month	11	17.0314	1.5483	10.11	**<.0001**
Tide (High, Medium, Low)	2	1.1036	0.5518	3.6	0.0286
Tidal Flow (Ebb, Flood, Slack)	2	0.7899	0.3949	2.58	0.0778
Day-Night	1	4.8011	4.8011	31.36	**<.0001**

Table 4-6. Mean impingement rates (# of organisms per million m^3) for different variables at the two intakes (+/- 95 percent confidence interval).

Units	Variable	Category	Impingement Rate
1, 2	Diel Light Regime	Day	114.9 (+/-127.5)
1, 2		Night	147.0 (+/-61.2)
1, 2	Tidal Flow	Ebb	155.6 (+/-93.6)
1, 2		Flood	69.3 (+/-19.1)
1, 2		Slack	167.9 (+/-176.7)
1, 2	Tide	High	73.1 (+/-48.2)
1, 2		Low	136.0 (+/-62.2)
1, 2		Mid	149.4 (+/-111.8)
3, 4	Diel Light Regime	Day	74.7 (+/-34.2)
3, 4		Night	266.6 (+/-212.6)
3, 4	Tidal Flow	Ebb	117.8 (+/-71.0)
3, 4		Flood	87.2 (+/-40.3)
3, 4		Slack	331.5 (+/-341.2)
3, 4	Tide	High	179.9 (+/-225.8)
3, 4		Low	162.9 (+/-103.2)
3, 4		Mid	186.9 (+/-188.1)

a)



b)

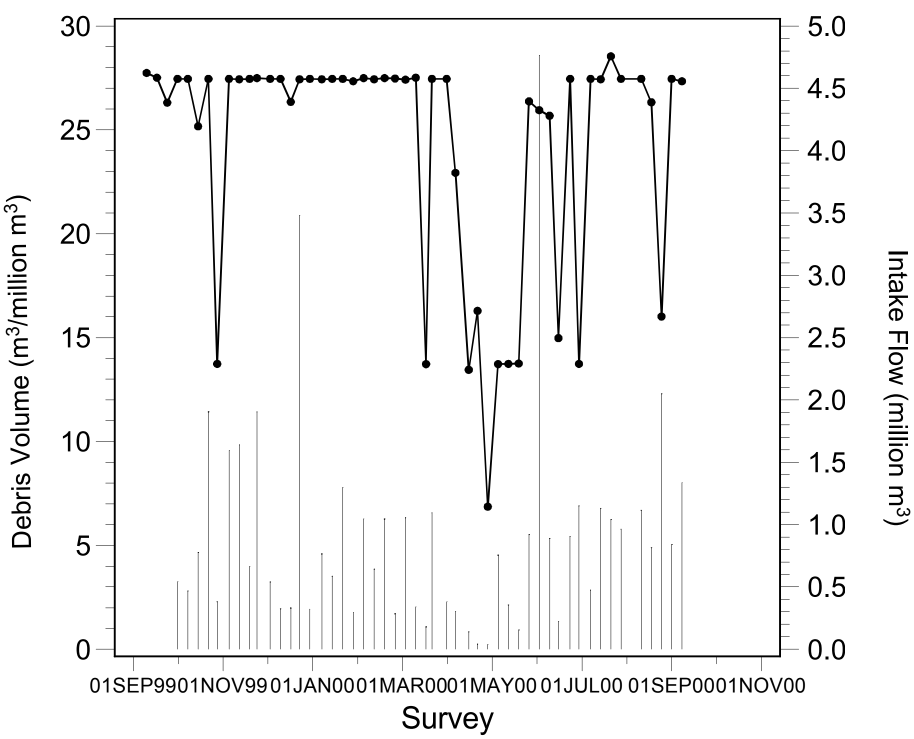
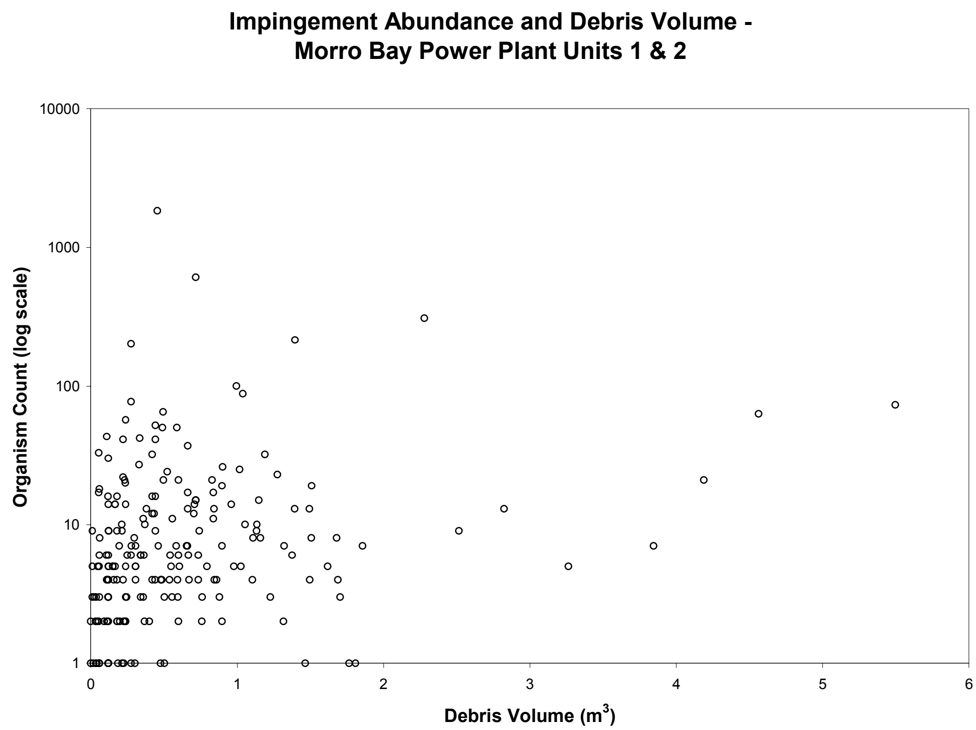


Figure 4-32. Estimated total intake flow (line with symbol) and debris rate (lines rising from x-axis) during each impingement survey for a) Units 1 and 2, and b) Units 3 and 4.

a)



b)

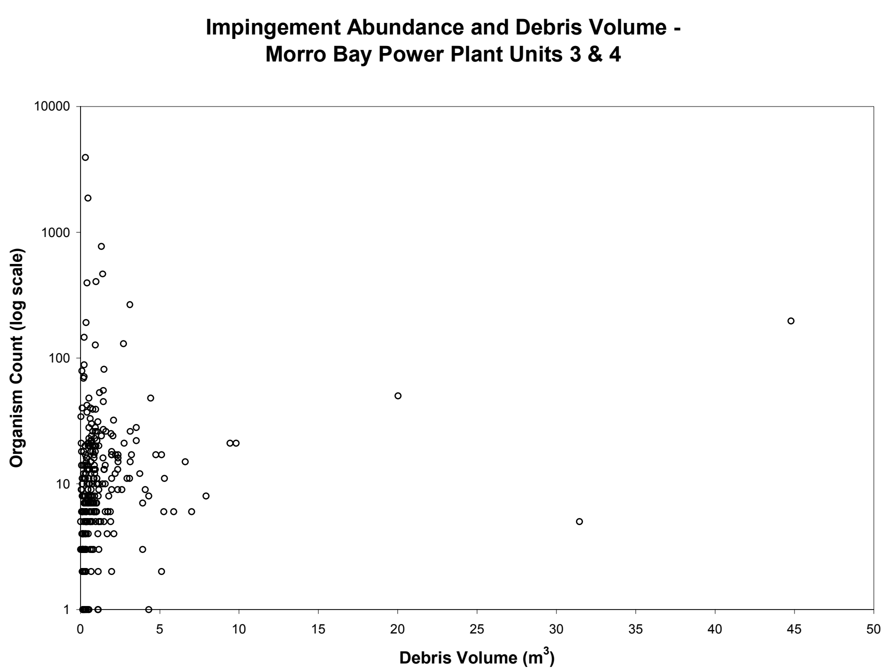
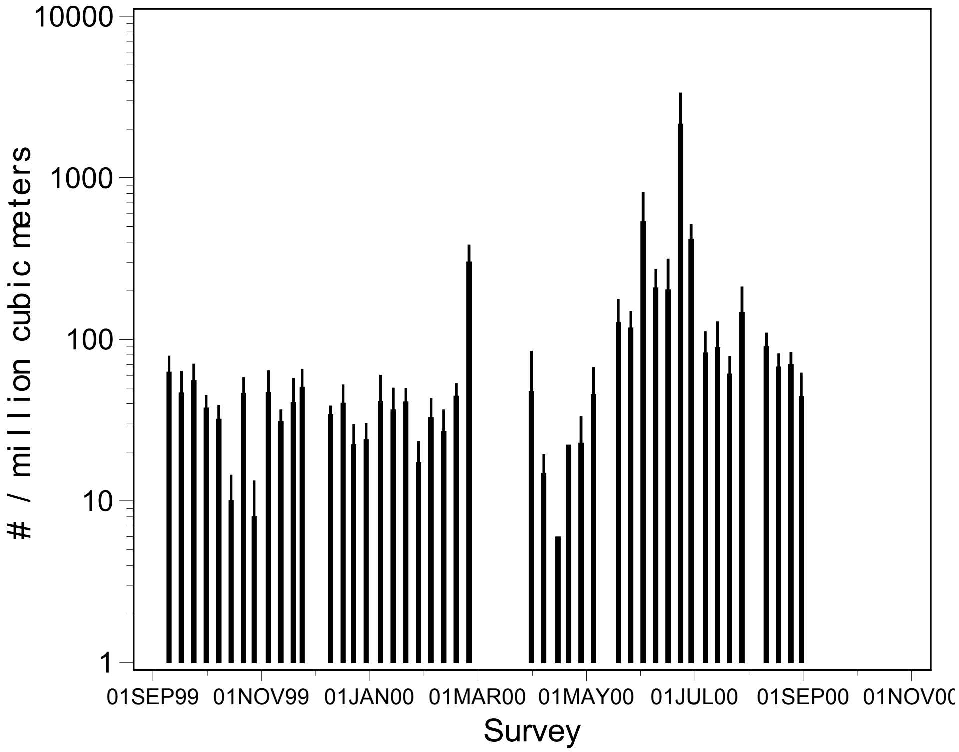


Figure 4-33. Counts of impinged fishes and invertebrates (graphed on log scale) collected between September 1999 and September 2000 plotted against impinged debris volume for a) Units 1 and 2 and b) Units 3 and 4 at Morro Bay Power Plant.

a) Units 1 and 2



b) Units 3 and 4

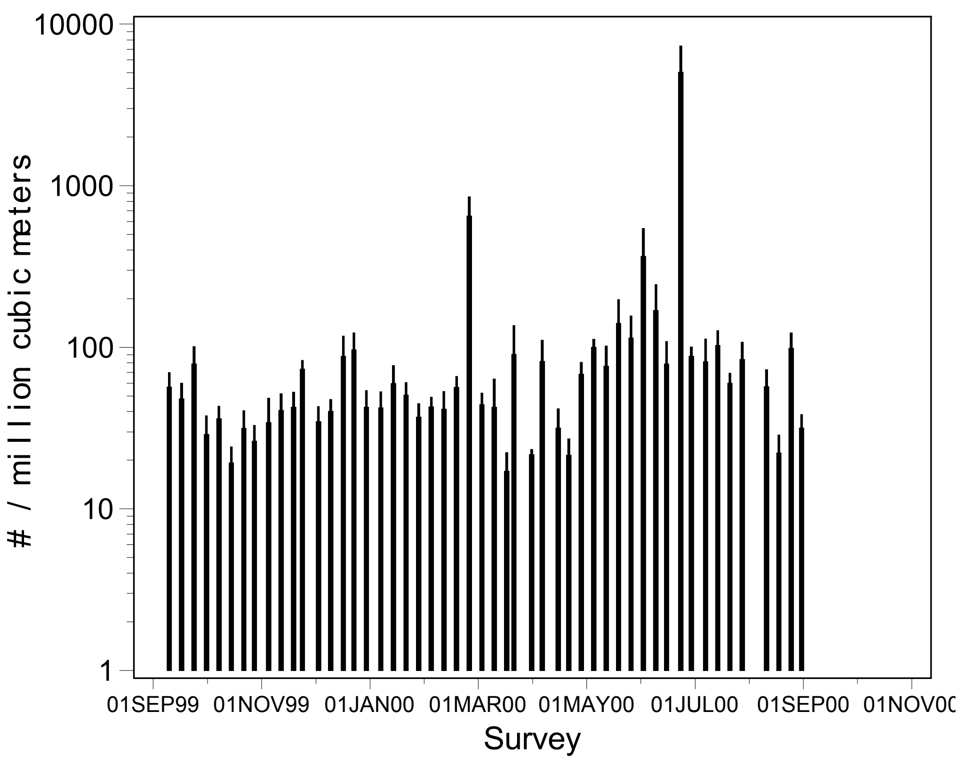


Figure 4-34. Average impingement rates (#/million m^3) for all organisms plus standard error during each impingement survey for a) Units 1 and 2, and b) Units 3 and 4.

4.7 Discussion

The total estimated impingement losses at the MBPP between September 1999 and September 2000 (expanded by cooling water flow volume) were around 74,000 fishes weighing 1.1 MT and around 53,000 selected macroinvertebrates weighing 0.4 MT. Several of the fishes and invertebrates impinged at MBPP have some commercial or recreational value either as food for human consumption, or as reduction (fish meal), live bait, or sport catch. These will be considered when assessing potential impacts of impingement (Section 5.0 in this document).

Animals that are impinged are often the early life stages that are weak swimmers or not yet fully developed. Many of the taxa that occur in local waters but are not impinged have some aspect of their life histories that provides refuge from entrapment in the plant's cooling water intake system. Thus, fishes and invertebrates whose early life stages progress primarily in habitats outside of Morro Bay (e.g., rockfishes) substantially reduce their risk of impingement. Animals that are small and weak swimming as adults are less likely to be impinged in large numbers if their habitat usage (e.g., pelagic or benthic environments) places them in areas away from the power plant intakes. Finally, some organisms are found primarily in bays and estuaries (e.g., topsmelt) and are often impinged. However, these organisms have other life history adaptations (e.g., fast growth, high fecundity, competent young) that allow them to sustain this added source of mortality while maintaining healthy population levels.

Previous studies in and around Morro Bay indicate that the fishes impinged at the MBPP are representative of the majority of fishes available from the surrounding habitats. Eighteen of the top twenty-five species collected in CDFG's Morro Bay otter trawls initiated in 1992 were collected during the 1999-2000 impingement survey at the MBPP. Similarly, nearly all of the invertebrates impinged at the MBPP are represented in CDFG otter trawl collections (CDFG unpubl. otter trawl data). The ten most abundant fish taxa collected by Fierstine et al. (1973) at various sites within Morro Bay (including near the harbor entrance) contain only two species not impinged at the MBPP; diamond turbot *Hypsopsetta guttulata* and tidewater goby *Eucyclogobius newberryi*. By contrast, several gobiids collected by Horn (1980) near Baywood in southern Morro Bay did not occur in the impingement collections.

There are several notable differences between the previous impingement study completed between July 1977 and December 1978 (Behrens and Sommerville 1982) and this study. During the previous study, almost 17,000 fishes were collected over a 12-month impingement sampling period, while approximately 11,000 fishes were collected during this study. Although several of the most abundant fishes in impingement collections were common to both studies, abundances of shiner perch *Cymatogaster aggregata* and bocaccio *Sebastes paucispinis* were much greater in the previous study. Over 1,100 juvenile bocaccio were collected during the previous study (only considers surveys from the same 12-month period of their 18-month study as that of the present study), while only two were collected during this study. Most of the bocaccio collected during the previous study were small juvenile fish that come in close to shore during their first year. The decline in the commercial take of bocaccio over the past decade has been well documented (MacCall et al. 1999, Parker et al. 2000) and probably accounts for the low abundance of juvenile bocaccio in this study.

The differences in the abundance of shiner perch between the two studies is even larger. During the 12-month sampling period of 1978, over 5,400 shiner perch were collected (Behrens and Sommerville 1982), while during this study only 45 were collected. Over 75 percent of the shiner perch impinged during the previous study were newborns (Behrens and Sommerville 1982). Annual indices for YOY shiner perch from the San Francisco Bay monitoring program show a decline from the early 1980s through the last data point in 1993 (CDFG, http://www.delta.dfg.ca.gov/baydelta/monitoring/shper.html). This decline is attributed to loss of saltwater marsh areas that are recognized as important nursery areas for this species. Female shiner perch will enter coastal bays prior to giving birth to utilize saltwater marsh and eelgrass beds as nursery areas (Bane and Robinson 1970). The reduction in the areal coverage of eelgrass beds in Morro Bay, especially in areas of the bay that are closer to the intake structures (Tetra Tech 1999) may partially account for the reduced numbers of shiner perch in impingement collections.

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5.0 COOLING WATER INTAKE SYSTEM IMPACT ASSESSMENT

The entrainment and impingement effects of the cooling water system for the proposed MBPP combined-cycle (CC) project have been assessed on the basis of both historical studies and twelve months of recently completed survey information. The assessment considers 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 CWIS effects on larval fishes and megalopal cancer crabs described in the MBPP Modernization Project Study Plan (Appendix A) were fecundity hindcasting (*FH*), adult equivalent loss (*AEL*), and empirical transport modeling (*ETM*). This report contains *ETM* estimates for all selected larval fishes and megalopal cancer crabs, and estimates of *FH* and *AEL* where data were available to parameterize these demographic approaches.

Results from the MBPP entrainment and source water studies were used to predict the potential effects of the proposed combined-cycle CWIS on larval fishes and megalopal cancer crab populations. Estimates of larval fish and megalopal cancer crab concentrations (#/m^3) sampled at the MBPP CWIS were multiplied by the projected weighted average of the new combined-cycle facility's intake volume (m^3) to provide estimates of potential entrainment. Similarly, larval fish and megalopal cancer crab concentrations estimated from MBPP's source water bodies (Morro Bay and Estero Bay) and multiplied by the daily tidal volume for Morro Bay, produced estimates of local larval and megalopal abundance. By comparing the number of larvae and megalopae withdrawn by the power plant to the number available (i.e., at risk to entrainment), an estimate of the conditional mortality due to entrainment (*PE*) can be generated for each taxon or species. These estimates of conditional mortality are combined in the *ETM* model to provide an estimate of the annual probability of mortality due to entrainment (P_m) that can be used for determining CWIS effects and the potential for long-term population declines. Fishery management practices and other forms of stock assessments provide the context required to interpret P_m. In the case of a harvested species, P_m must be considered in addition to these harvest losses when assessing impacts and any potential for population decline.

Present-day findings on the MBPP CWIS entrainment effects and projected effects of the new combined-cycle facility were reviewed and assessed for ten of the most abundant larval fish taxa and all megalopal cancer crabs. Seven fish taxa comprised nearly 90 percent (by number) of the larvae entrained. Population level effects on the third most abundant taxon, the northern lampfish *Stenobrachius leucopsarus*, could not be modeled because information on the early life history of this taxon was not found in the literature. The northern lampfish is very widespread, occurring in the California Current system from northern Baja California to the Bering Sea and Japan (Miller and Lea 1972). No commercial or recreational fishery exists for this species or for most of the other taxa that comprised over 90 percent of the number of larval fish entrained.

On the other hand, this assessment has included three commercially and recreationally important species even though they each represented less than one percent of the total number of larval fishes entrained. These species were white croaker *Genyonemus lineatus* (0.72 percent), Pacific herring *Clupea pallasii* (0.63 percent), and cabezon *Scorpaenichthys marmoratus* (0.56 percent). Following this assessment of the MBPP CWIS effects, a variety of alternative intake technologies for reducing these entrainment and impingement effects are reviewed in Section 6.0—Evaluation of Alternative Intake Technologies. Both the feasibility and cost of the various technologies were weighed against their effectiveness in reducing any identified CWIS effects or potential impacts, provided cost is not wholly disproportionate to the benefit.

5.1 Entrainment Effects Assessment

For this report, we have focused our assessment of entrainment effects on the most abundant and on commercially or recreationally important fish taxa and all cancer crabs. Larval fishes analyzed were the unidentified gobies, Pacific staghorn sculpin, northern lampfish, shadow goby, combtooth blennies, the kelp/gopher/black-and-yellow (KGB) rockfish complex, and jacksmelt. These taxa comprised nearly 90 percent of all the entrained larval fishes (Table 5-1). The white croaker, Pacific herring, and cabezon, which occurred in lower abundances, were included in the assessment because they represented species of commercial or recreational importance (Table 5-1). However, as discussed in the following assessment of these three species, their low abundance made it difficult to quantitatively assess any MBPP entrainment effects or potential population-level impacts. The *Cancer* spp. megalopae assessed were brown rock crab, hairy rock crab, yellow crab, slender crab, red rock crab, and Dungeness crab (Table 5-2). The brown rock crab, yellow crab, red rock crab, and Dungeness crab all have some commercial importance, while the hairy rock crab and slender crab do not.

This assessment first evaluates the effects of the MBPP CWIS entrainment on larval fishes and megalopal cancer crabs, followed by an assessment of impingement effects and the potential reduction of these effects by intake technology alternatives to the new MBPP combined-cycle intake structure and cooling water flows.

Table 5-1. Annual estimates of total entrainment based on new combined-cycle cooling water volumes for all larval fishes for January – December 2000.

Common Name	Taxon	Estimated Annual # of Entrained Larvae	Standard Error	Percent of Total Entrainment (%)
gobies	Gobiidae unid.	393,261,027	4,044,070.90	77.37
Pacific staghorn sculpin	*Leptocottus armatus*	17,321,398	291,966.18	3.41
northern lampfish	*Stenobrachius leucopsarus*	14,548,803	473,519.04	2.86
shadow goby	*Quietula y-cauda*	13,503,587	696,628.94	2.66
combtooth blennies	*Hypsoblennius* spp.	10,042,151	231,612.25	1.98
KGB rockfishes	*Sebastes* spp. V_De	6,406,622	188,985.02	1.26
jacksmelt	*Atherinopsis californiensis*	6,266,107	284,014.38	1.23
blackeye goby	*Coryphopterus nicholsii*	3,777,821	170,522.33	0.74
longjaw mudsucker	*Gillichthys mirabilis*	3,286,095	118,195.10	0.65
bay goby	*Lepidogobius lepidus*	3,233,197	132,385.02	0.64
Pacific herring	*Clupea pallasii*	3,030,431	51,487.49	0.60
white croaker	*Genyonemus lineatus*	2,992,511	116,313.76	0.59
cabezon	*Scorpaenichthys marmoratus*	2,888,498	137,150.77	0.57
silversides	Atherinidae unid.	2,719,944	140,779.44	0.54
topsmelt	*Atherinops affinis*	2,574,977	105,876.20	0.51
rockfishes	*Sebastes* spp. V	2,452,533	105,291.85	0.48
blue lanternfish	*Tarletonbeania crenularis*	2,212,908	99,363.93	0.44
northern anchovy	*Engraulis mordax*	2,135,787	102,260.28	0.42
larval fish - damaged	larval fish - damaged	1,283,324	78,644.31	0.25
clinid kelpfish	*Gibbonsia* spp.	1,140,737	49,980.69	0.22
ronquils	Bathymasteridae unid.	1,118,752	53,775.61	0.22
sculpins	Cottidae unid.	1,009,206	56,795.66	0.20
smoothhead sculpin	*Artedius lateralis*	739,011	54,752.38	0.15
sculpin	*Oligocottus* spp.	620,093	36,881.46	0.12
pricklebacks	Stichaeidae unid.	615,886	41,871.75	0.12
tube blennies	Chaenopsidae unid.	550,501	40,811.41	0.11
monkeyface eel	*Cebidichthys violaceus*	505,467	48,500.03	0.10
popeye blacksmelt	*Bathylagus ochotensis*	494,554	34,487.18	0.10
sculpins	*Artedius* spp.	455,238	31,774.31	0.09
wooly sculpin	*Clinocottus analis*	443,530	33,981.93	0.09
unidentified species	larval/post-larval fish, unid.	406,824	39,869.52	0.08
painted greenling	*Oxylebius pictus*	373,259	30,104.06	0.07
smelts	Osmeridae unid.	364,054	21,980.57	0.07
rockfishes	*Sebastes* spp. VD	353,631	30,771.03	0.07
blind goby	*Typhlogobius californiensis*	347,224	33,609.05	0.07
pipefishes	*Syngnathus* spp.	344,816	30,209.59	0.07
snubnose sculpin	*Orthonopias triacis*	338,578	34,929.81	0.07
snailfishes	*Liparis* spp.	326,003	25,672.27	0.06
roughcheek sculpin	*Ruscarius creaseri*	275,533	33,183.25	0.05
righteye flounders	Pleuronectidae unid.	266,884	26,765.31	0.05
starry flounder	*Platichthys stellatus*	266,824	20,096.04	0.05
rockfishes	*Sebastes* spp.	239,169	29,044.28	0.05
Pacific sandlance	*Ammodytes hexapterus*	221,882	26,265.77	0.04
rockfishes	*Sebastes* spp. V_D	212,813	32,901.44	0.04
Pacific sanddab	*Citharichthys sordidus*	189,540	17,027.56	0.04
gunnels	Pholididae unid.	134,989	16,541.98	0.03

Table 5-1 (continued). Annual estimates of total entrainment based on new combined-cycle cooling water volumes for all larval fishes for January – December 2000.

Common Name	Taxon	Estimated Annual # of Entrained Larvae	Standard Error	Percent of Total Entrainment (%)
labrisomid kelpfishes	Labrisomidae unid.	130,625	23,132.64	0.03
greenlings	Hexagrammidae unid.	130,497	21,994.79	0.03
bay pipefish	*Syngnathus leptorhynchus*	126,957	17,024.21	0.02
blennies	Blenniidae	117,086	19,118.32	0.02
California halibut	*Paralichthys californicus*	100,329	15,586.11	0.02
speckled sanddab	*Citharichthys stigmaeus*	97,108	17,500.81	0.02
English sole	*Parophrys vetulus*	91,928	11,143.03	0.02
croakers	Sciaenidae unid.	87,979	15,553.91	0.02
clingfishes	*Gobiesox* spp.	86,615	18,657.05	0.02
poachers	Agonidae unid.	86,165	15,905.32	0.02
prickly sculpin	*Cottus asper*	85,742	16,987.82	0.02
rock sole	*Pleuronectes bilineatus*	79,358	19,520.08	0.02
pipefishes	Syngnathidae unid.	59,729	12,314.49	0.01
tidepool sculpin	*Oligocottus maculosus*	57,168	15,601.32	0.01
broadfin lampfish	*Nannobrachium ritteri*	52,713	11,425.56	0.01
sand sole	*Psettichthys melanostictus*	51,915	11,405.42	0.01
lefteye flounders	Paralichthyidae unid.	40,213	10,749.97	0.01
Pacific sardine	*Sardinops sagax*	39,714	15,010.53	0.01
rockfishes	*Sebastes* spp. V_D_	39,528	4,965.07	0.01
tubesnout	*Aulorhynchus flavidus*	38,690	9,372.33	0.01
sanddabs	*Citharichthys* spp.	35,396	13,378.45	0.01
rockfishes	*Sebastes* spp. V_	34,617	9,327.00	0.01
queenfish	*Seriphus politus*	31,563	8,510.43	0.01
fringeheads	*Neoclinus* spp.	31,525	8,469.22	0.01
flatfishes	Pleuronectiformes	29,598	7,964.79	0.01
diamond turbot	*Hypsopsetta guttulata*	20,885	6,297.08	<0.01
ribbonfishes	Trachipteridae	17,671	6,678.89	<0.01
Pacific hake	*Merluccius productus*	17,082	5,693.84	<0.01
lampfishes	*Nannobrachium* spp.	16,379	6,686.77	<0.01
combfishes	*Zaniolepis* spp.	15,565	5,883.00	<0.01
red brotula	*Brosmophycis marginata*	15,431	5,832.39	<0.01
medusafish	*Icichthys lockingtoni*	15,374	5,810.74	<0.01
lanternfishes	Myctophidae unid.	14,187	5,362.17	<0.01
longfin lanternfish	*Diogenichthys atlanticus*	14,098	5,328.55	<0.01
sculpin	*Ruscarius* spp.	14,036	5,305.29	<0.01
hatchet fishes	*Sternoptyx* spp.	13,957	5,275.24	<0.01
herrings	Clupeiformes	13,772	5,205.32	<0.01
grunts	Haemulidae unid.	13,674	5,168.30	<0.01
hornyhead turbot	*Pleuronichthys verticalis*	13,079	4,943.29	<0.01
sculpin	*Icelinus* spp.	13,049	4,931.97	<0.01
aurora rockfish	*Sebastes aurora*	12,295	5,019.42	<0.01
Total Larvae		526,086,300		

Table 5-2. Annual estimates of total entrainment based on new combined cycle cooling water volumes for all crab megalopae for January – December 2000.

Common Name	Taxon	Estimated Annual # of Entrained Larvae	Standard Error	Percent of Total Entrainment (%)
brown rock crab	*Cancer antennarius*	9,744,688	224,772	71.8
hairy rock crab	*Cancer jordani*	1,965,950	119,801	14.5
yellow crab	*Cancer anthonyi*	1,116,099	51,687	8.2
slender crab	*Cancer gracilis*	470,025	35,475	3.5
Cancrid crabs	*Cancer spp.*	140,217	19,024	1.0
red rock crab	*Cancer productus*	85,705	14,570	0.4
Dungeness crab	*Cancer magister*	54,650	12,002	0.6
Total Megalopae		13,577,334		

5.1.1 Source Water Volume

The calculation of *ETM*, illustrated in Equations 9 to 14 in the Study Plan (Appendix A) requires that several parameters be obtained for each taxon being modeled. These include estimates of the number of entrained larvae and megalopae, the number of larvae and megalopae in the source water population at risk to entrainment, and an estimate of the period of time that the larvae are subject to entrainment. The number of larvae and megalopae entrained was estimated by multiplying estimates of entrainment concentrations by the weighted average volume of the power plant's intake over a 24-hour tidal period. The number of source water larvae and megalopae at risk was estimated by multiplying concentrations of source water population samples by the volume of source water. Examples of the *ETM* calculation using combtooth blenny and KGB rockfish data are attached to Appendix A.

The MBPP source water area was divided into two sub-areas for the purposes of study and analysis. Information on the marine geography, hydrography, and ecology was employed in Technical Working Group (TWG) discussions to define two sub-elements of the source water population at risk to entrainment. The defined elements of the source water population were Estero Bay and Morro Bay. The shallow tidal channels and tributaries of Morro Bay flood and drain extensive pickleweed marsh, eelgrass beds, and mudflats that provide habitat for assemblages of invertebrates and fishes characteristically different from those found offshore in Estero Bay. Larval fish and megalopal cancer crab data from stations 1–4 were combined to represent Morro Bay source water concentrations, and data from stations 1 and 5 were combined to compute source water estimates for ocean source water (i.e., Estero Bay). A combination of the sampling results from stations 1, 2, and 5 approximate tidally mixed source water between bay and ocean concentrations. Data from the MBPP intake station (Station 2) were used in calculating source water estimates because they also provided another estimate of the larval concentration in Morro Bay.

The volume of the Morro Bay source water used to calculate the proportional entrainment (*PE*) values for the *ETM* model used for the MBPP project is the sum of the bay's twice daily exchange of its 12,560 acre-ft tidal prism, adjusted for tidal exchange, (Mean High Water [MHW] to Mean Low Water [MLW]) and the bay's non-tidal volume of 4,394 acre-ft. The volume of the bay's tidal prism has been calculated by a number of investigators, each one reporting somewhat different findings. The earliest estimates were made by the Army Corps of Engineers, and the most recent by Tetra Tech, Inc., consultants to the Morro Bay National Estuary Program (MBNEP). Duke Energy retained Dr. David Jay to undertake a study of the various estimates and to provide a best estimate of the bay's tidal prism volume to the TWG. Dr. Jay's findings are used in this report's *PE* calculations and are also included as Appendix E of this report.

The members of the TWG reasoned that the sum of daily tidal prism volumes included a volume of Morro Bay outflow that returned with the incoming tide. Since the volume is used to estimate the total supply of entrained larvae, the inclusion of the re-circulated tidal prism volume would double count a portion of total larval supply and underestimate the potential entrainment effects. The TWG members discussed various methods for calculating *PE* in order to adjust for bias, including a recommendation for adding a term for combining sampling station data.

Dr. Jay, one of the TWG's consulting oceanographers, provided a hydrodynamic solution for the ratio of tidal exchange using a method published in the scientific literature, the "Tidal Exchange Ratio." The tidal exchange ratio (TER) is the fraction of the total tidal exchange that consists of "new" water coming into the estuary, i.e., water that did not leave the estuary on the previous tidal cycle. In Morro Bay, the "total tidal exchange" is synonymous with the tidal prism, except for the amount estimated by TER. We used the solution recommended in Dr. Jay's report to correct the bay's tidal exchange volume for re-circulation.

The TER is difficult to estimate from measurements because the currents that prevail outside of any estuary mouth are complex and variable, and it is quite sensitive to processes inside the estuary, especially river inflow and density stratification. However, a method was developed (Largier et al. 1996) that measures the TER from the change in salinity of water flowing in and out of the entrance of a positive estuary. Applying this method to Tetra Tech data reported to the MBNEP (Tetra Tech 1999), Dr. Jay calculated the Morro Bay TER to be between 70 and 80 percent of the average daily tidal prism. The midpoint of Dr. Jay's calculation, 75 percent, was used in calculating the *PE* estimates used in the *ETM*. Using this value in the study plan's

PE formulation, the daily tidal volume of Morro Bay is equal to 75 percent of the sum of the twice daily tidal exchange of a volume equal to the average tidal prism added to the bay's non-tidal volume. TER is assumed to be constant with zero variance, therefore the study plan's variance formulations were unaffected by its inclusion in the *PE* formulae. Dr. Jay's report on the method used to calculate the TER and the results of his application of the method for Morro Bay are included as Appendix C of this report.

	Volume (m^3)	Volume (gal)
Estero Bay Study Area	20,915,551	5,525,304,000
Morro Bay	15,686,663	4,143,978,000
Combined-Cycle Units (maximum volume)	1,619,190	427,744,800

The Empirical Transport Model (*ETM*) estimates of P_m are presented along with *PE* estimates for the January – December 2000 source water surveys. *PE* values from each source water survey were used in calculating P_m. In computing P_m, *PE*'s were weighted by the i^{th} monthly survey fraction (f_i) of the source water population at risk. This value was the monthly fraction of total annual entrainment for the source water survey period. This factor can bias the estimate of P_m when the f_i is not representative of the source water population at risk.

The length of time that a larval fish is in the plankton and subject to entrainment is important in *ETM* calculations. Length measurements taken from representative samples of the larval fish taxa presented in Section 3.0 were used to estimate the number of days that larvae (for a specific taxon) were at risk to entrainment. Reports on larval duration from the scientific literature are unlikely to accurately reflect the period of time that larvae are exposed to entrainment. This is because of ontogenetic changes during larval development that result in increased swimming ability or behavioral changes. Possible outliers were eliminated by basing the minimum and maximum lengths on the central 98 percent of the length distribution for a taxon and dropping the lengths of the top and bottom percentiles. Estimates of larval growth rates (mm/day) were then used with this size range to estimate the number of days the larvae were exposed to entrainment. The estimates of growth rates and their source from the literature are presented in the following impact assessment sections for the different taxa. The average duration of entrainment risk for a taxon was calculated from the bottom percentile value to the mean value, while the maximum duration was calculated from the bottom percentile value to the 99 percentile value. Our estimates of the period of entrainment risk for cancer crabs were derived from literature values on the average age of the megalopal stage for each crab species.

While the majority of the taxa entrained by the MBPP are common to California's bay and estuarine habitats, other fish taxa and many of the cancer crabs reside primarily in California's nearshore, open-coast habitats found outside Morro Bay. Therefore, the *ETM* model was adjusted to not only estimate incremental mortality as a proportion of a local population, but to estimate losses to a coastally distributed taxa by scaling up to a larger population of inference. The following modified form of the *ETM* model was proposed to account for sampling only a local fraction of a coastwide source water body:

$$P_m = 1 - \sum_{i=1}^{12} f_i \cdot (1 - PE_i \cdot P_S)^d$$

with P_s representing the proportion of the sampled waterbody (Boreman et al. 1981, MacCall et al. 1983). P_s was calculated as

$$P_S = \frac{N_L}{N_T}$$

where N_L represents the sampled source water population and N_T represents the population of inference. This formula for *ETM* was used for fish and crab taxa whose distributions extend out into the nearshore waters. Estimates of the population of inference for these taxa were unavailable.

P_s can also be calculated using an estimate of the larval or adult population in the study area, defined by Ricker (1975), as the proportion of the parental stock. If the distribution in the larger area is assumed to be uniform, then the value of P_s for the proportion of the population will be the same as the value computed based on area or volume. Therefore, P_s was estimated using the distance the larvae could have traveled based on the duration of exposure to entrainment and current speed. A current speed of 11.2 cm/sec (4.21 in./sec) was calculated from hourly measurements over the period of January 1, 1996 – May 31, 1999 taken at a single InterOceans S4™ current meter deployed at a depth of -6 m (-19.8 ft) MLLW in approximately 30 m (99 ft) of water about 1 km (0.6 mi) west of the Diablo Canyon Power Plant Intake Cove, south of Morro Bay. The current direction was ignored in the calculations, but was predominately alongshore. The current speed was used to estimate unidirectional displacement over the period of time that the larvae were exposed to entrainment. The value of alongshore displacement (N_T) was compared with the alongshore length of the sampled waterbody (N_L). The distance between the west Morro Bay breakwater and Station 5 is 3.0 mi (4.8 km); a value of 6.0

mi (9.6 km) (twice the distance) was used for N_L. This value was used because it places Station 5 in the center of the sampled waterbody.

We present only a single estimate of P_m for the taxa that used an adjustment for P_s in the *ETM* model. This is because the increase in P_m due to the extended duration, is proportionally offset by the size of the population area due to the larger extended estimate of alongshore distance. The estimate of the standard error is increased due to the extended period of entrainment risk, so two estimates of the standard error are presented for these taxa.

5.1.2 Demographic Approaches for Estimating Entrainment Effects

Entrainment losses were also estimated from total larval and megalopal entrainment at the MBPP using *FH* and *AEL* models. These models require species-specific estimates of age, growth, fecundity, and survivorship. These data were available for six of the ten target fish taxa: unidentified gobies, shadow goby, combtooth blenny, KGB rockfish complex, white croaker, and Pacific herring. Estimates of survival for the arrow goby *Clevelandia ios* were used for the unidentified goby category. Adult arrow goby are very abundant in Morro Bay (Fierstine et al. 1973, Horn 1980, CDFG unpubl. otter trawl data) and probably represent a large proportion of the “unidentified goby” taxa group. Several unidentified goby specimens collected in our entrainment and source water samples were confirmed by DNA analysis to be arrow goby (i.e., the “unidentified goby” DNA matched arrow goby DNA sequences). For the other fish and all crab taxa, either species-specific fecundity or mortality rates were available to parameterize both approaches for estimating entrainment effects. The literature sources for the demographic information frequently did not include any estimates of variance, therefore a variance to mean ratio (coefficient of variation) of 30 percent was assumed in the absence of a published value. The sources of the available life history data were summarized, along with the impact assessment for each taxon, in the following sections.

5.1.3 Individual Taxa Results

5.1.3.1 Unidentified Gobies

Based on the estimate of annual total entrainment of all fish larvae, the unidentified goby category comprised an estimated 77 percent, the largest percentage of any group (Table 5-1). The annual estimate of entrainment for January – December 2000 was 393,261,027 larvae (*S.E.* = 4,044,071) (Table 5-1). Arrow goby probably comprised the majority of the larvae in this category. Taxonomic examinations of our samples have 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). All five of the unidentified Gobiidae larvae sent out for genetic analysis were identified as arrow goby (Appendix G, Report on DNA Analysis).

This finding brings out a very important point in the application of impact assessment methods. Although we can analyze the proportional loss of a taxa group such as unidentified gobies, it is not possible to assign the significance of these losses to a population unless we know the species. 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 this taxa group may contain more than a single species, if the relative proportion of each species in the unidentified category remains the same among entrainment and source water samples, our estimate of CWIS effects and impacts is unaffected. We simply will not know to what species they apply.

Empirical Transport Model (ETM)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate the period of entrainment risk for unidentified gobies using a growth rate for larval blackeye goby *Coryphopterus nicholsii* (0.27 mm/day [0.01 in./day]) reported by Steele (1997). The range from 2.5 to 8.1 mm (0.1 to 0.3 in.) was used to estimate a maximum period of entrainment risk of 20.7 days, while the duration to the mean length of 3.7 mm (0.15 in.) was estimated as 4.3 days.

The estimates of P_m for unidentified gobies ranged from 0.11 (*S.E.* = .33) for the average duration of larval exposure (4.3 days) to 0.43 (*S.E.* = .55) for the maximum duration of larval exposure (20.7 days). The model did not include an adjustment for P_s because this taxa group is primarily composed of species that utilize the bay and estuarine habitats within Morro Bay. *PE* estimates ranged from 0.0098 to 0.0736 (Table 5-3). The largest fractions of the population were collected during the June (f_i = 0.1695) and February (f_i = 0.1524) surveys (Table 5-3).

Table 5-3. *ETM* data for unidentified gobies Gobiidae. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0297	0.0083	0.0221	0.0011
28-Feb-00	0.0291	0.0099	0.1524	0.0037
27-Mar-00	0.0736	0.0079	0.0972	0.0027
24-Apr-00	0.0220	0.0060	0.1062	0.0039
15-May-00	0.0307	0.0040	0.0819	0.0028
12-Jun-00	0.0207	0.0029	0.1695	0.0037
10-Jul-00	0.0208	0.0028	0.0721	0.0022
08-Aug-00	0.0181	0.0039	0.0367	0.0009
05-Sep-00	0.0098	0.0018	0.0487	0.0022
02-Oct-00	0.0324	0.0052	0.0447	0.0017
13-Nov-00	0.0166	0.0028	0.1091	0.0044
18-Dec-00	0.0399	0.0082	0.0596	0.0018

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 (Table 5-1). The parameters required for formulation of the *FH* estimate for unidentified gobies were compiled from references on arrow goby (Brothers 1975, Wang 1986). No estimates of egg survival for gobies were available, but egg masses in gobies are demersal and attached to the substrate (Wang 1986). Parental care, usually provided by the adult male, is common in the family (Moser 1996), and therefore, egg survival is probably high and assumed to be 100 percent. Although no estimate of larval survival is available, Brothers (1975) states that 98.3 percent larval mortality over two months is a reasonable estimate for arrow goby. Daily survival was therefore estimated as $(1\text{-}0.983)^{6\,/\,365.25} = 0.935^{d\text{-}1}$ (the value for survival was estimated using an exponent of 6/365.25 because there are six two-month periods within a year). Survival to entrainment was then estimated using the mean number of days to entrainment (4.3 days) as $0.935^{4.25} = 0.75$. A batch fecundity estimate of 875 eggs was used based on Wang's (1986) estimates for arrow goby (750 to 1,000 eggs). Brothers (1975) reports that gobies may spawn multiple times during the year, so an estimate of two spawns per year was used in calculating *FH* (875 eggs/spawn × 2 spawns/year = 1,750 eggs). Brothers (1975) states that mortality after the first year is high and a large percentage of the females are reproductive during the first year. Therefore, values for longevity and age at maturity of 2.0 years and 0.5 year, respectively, were used in the model. The number of adult females hindcast was 398,149 (90 percent C.I. = 150,428 to 1,053,810) (Table 5-4)

Table 5-4. Annual estimates of female adult unidentified goby losses based on larval entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	398,149	235,584	1,053,810	150,428	903,382
Entrainment	393,261,027	4,044,071	404,884	391,414	13,470
Larval survival	0.7525	0.2258	652,183	299,627	352,556
# Eggs/year	1,750	525	652,183	243,064	409,119
Longevity	2.0	0.6	828,358	215,132	613,226
Maturation	0.5	0.15	505,701	352,394	153,307

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

Adult Equivalent Loss (AEL)

The parameters required for formulation of *AEL* estimates for unidentified gobies include larval survival from entrainment to settlement and survival from settlement to age 1.25 years (the average age of the adults between ages 0.5 and 2.0 years). Larval survival from entrainment to settlement (60 days) was estimated as $0.935^{60-4.25} = 0.0239$ using the same daily survival rate used in formulating *FH*. Brothers (1975) estimated that annual mortality for arrow goby through the first year was approximately 91 percent and 99 percent thereafter. Therefore, the daily survival rate through the first year was estimated as $0.992 = (1\text{-}0.91)^{(1/365.25\text{-settlement})}$, while daily survival through the average female age of 1.25 years used in *FH* was estimated as 0.987. Survival estimates for these two periods were 0.090 and 0.316, respectively. The estimated number of equivalent adults corresponding to the number of larvae that would have been entrained by the proposed MBPP combined-cycle intakes was 267,850 (90 percent C.I. = 113,919 to 629,773) (Table 5-5).

Table 5-5. Annual estimates of adult unidentified goby losses due to entrainment using Adult Equivalent Loss model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *AEL*	Lower Estimate of *AEL*	*AEL* Range
Adult Equivalents	267,850	139,206	629,773	113,919	515,854
Total Entrainment	393,261,027	4,044,071	272,381	263,319	9,062
Early Larval Survival	0.0239	0.0072	438,748	163,518	275,230
Late Larval Survival	0.0899	0.0270	438,748	163,518	275,230
Pre-Recruit Survival	0.3162	0.0949	438,748	163,518	275,230

Summary

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 fishery or population data that can be used to compare harvest mortality rates to entrainment mortality rates and provide some context for the *ETM*, *FH*, or *AEL* results. Although P_m estimates indicate that the power plant may annually entrain an average of 11 percent (*S.E.* = 33) to a maximum of 43 percent (*S.E.* = 55) of unidentified goby larvae from the MBPP source water, there are no independent population estimates to help determine if this loss has resulted in any long-term effects on the local population. The only context for estimates of P_m are the *FH* and *AEL* results that showed that the incremental mortality due to entrainment may be equivalent to the loss of approximately 398,000 adult females and 268,000 adults, respectively.

There is a large difference between the *FH* and *AEL* estimates based on the relationship of $2FH \equiv AEL$. The *AEL* model used a daily survival rate for age one and older fishes that is lower than the survival rate for younger fishes (Brothers 1975). This would reduce the numbers of adult fishes in the older age classes that are being extrapolated by the *AEL* model.

5.1.3.2 Pacific staghorn sculpin

Based on the estimate of annual total entrainment of all fish larvae, Pacific staghorn sculpin comprised an estimated 3.4 percent of the larvae entrained (Table 5-1). The annual estimate of entrainment for January – December 2000 was 17,321,398 (*S.E.* = 291,966) (Table 5-1).

Empirical Transport Model (*ETM*)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate the period of entrainment risk for Pacific staghorn sculpin. A growth rate of 0.25 mm/day (0.01 in./day) (reported as R.W. Morris personal communication in Jones 1962) was used to convert length frequency analysis results to estimate the duration of entrainment exposure. The range from 3.6 to 9.8 mm (0.14 to 0.39 in.) was used to estimate a maximum period of entrainment risk of 25.0 days, while the duration to the mean length of 7.5 mm (0.30 in.) was estimated as 15.5 days. These values are considerably less than the approximately eight weeks between hatching and metamorphosis of larvae into juveniles that occurs at a length of 15 to 20 mm (0.6 to 0.8 in.) TL (Matarese et al. 1989).

Estimated P_m for Pacific staghorn sculpin was 0.05 (*S.E.* = 0.883 to 1.12) for the period of entrainment exposure applied in the model (15.5 and 25.0 days). The model included an adjustment for P_s because this taxon occupies both bay and nearshore habitats that extend beyond the sampling areas. *PE* estimates ranged from 0.0000 to 0.1882 (Table 5-6). The largest fractions of the population were collected during the January (f_i = 0.2376) and April (f_i = 0.2908) surveys (Table 5-6).

Table 5-6. *ETM* data for Pacific staghorn sculpin *Leptocottus armatus*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0082	0.0027	0.2376	0.0091
28-Feb-00	0.0561	0.0254	0.1534	0.0064
27-Mar-00	0.0755	0.0180	0.0519	0.0038
24-Apr-00	0.0975	0.0102	0.2908	0.0070
15-May-00	0.1162	0.0235	0.0497	0.0023
12-Jun-00	0.0000	0.0000	0.0130	0.0014
10-Jul-00	0.0000	0.0000	0.0000	0.0000
08-Aug-00	0.1882	0.2307	0.0027	0.0008
05-Sep-00	0.0000	0.0000	0.0015	0.0006
02-Oct-00	0.0261	0.0274	0.0016	0.0005
13-Nov-00	0.0072	0.0045	0.0796	0.0037
18-Dec-00	0.0341	0.0223	0.1181	0.0048

Fecundity Hindcast Model (*FH*)

No independent estimate of survival of Pacific staghorn sculpin between egg to entrainment age was found in the literature, and therefore, *FH* could not be calculated for this taxon.

Adult Equivalent Loss (*AEL*)

No independent estimate of survival of Pacific staghorn sculpin between age of entrainment and the adult stage was found in the literature, and therefore, *AEL* could not be calculated for this taxon.

Summary

While the Pacific staghorn sculpin sustains a minor commercial bait fishery in the Monterey Bay area, no such fishery exists in Morro Bay. There are no local fishery data that can be used to compare harvest mortality rates to entrainment mortality rates and provide some context for P_m estimates that indicate that the power plant may annually entrain approximately 5 percent (*S.E.* = 88 to 1,122) of the Pacific staghorn sculpin larvae from the local population. This small incremental increase in mortality to the local larval population is unlikely to result in any long-term impacts to Pacific staghorn sculpin.

5.1.3.3 Northern lampfish

Based on the estimate of annual total entrainment of all fish larvae, northern lampfish comprised an estimated 2.9 percent of the larvae entrained (Table 5-1). The annual estimate of entrainment for January – December 2000 was 14,548,803 larvae (*S.E.* = 473,519) (Table 5-1).

Empirical Transport Model (*ETM*)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate the period of entrainment risk for northern lampfish. A growth rate of 0.19 mm/day (0.01 in./day) was used to convert length frequency analysis results to estimate the duration of entrainment exposure. This is the average of two growth rates reported by Methot (1981) who calculated growth rates of 0.11 mm/day (0.04 in./day) for 5 mm (0.2 in.) larvae and 0.28 mm/day (0.01 in./day) for 15 mm (0.6 in.) larvae. The length range from 3.3 to 8.7 mm (0.13 to 0.34 in.) was used to estimate a maximum period of entrainment risk of 28.0 days, while the duration to the mean length of 4.7 mm (0.19 in.) was estimated as 7.2 days.

Estimated P_m for northern lampfish was 0.02 (*S.E.* = 0.413 to 0.822) for the periods of entrainment risk applied in the model (7.2 and 28.0 days). The model included an adjustment for P_s because this taxon occupies primarily nearshore and offshore habitats that extend well beyond the sampling areas. *PE* estimates ranged from 0.0000 to 0.0969 (Table 5-7). The largest fractions of the population were collected during the January (f_i = 0.6719) and April (f_i = 0.2055) surveys (Table 5-7).

Table 5-7. *ETM* data for northern lampfish *Stenobrachius leucopsarus*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0138	0.0029	0.6719	0.0119
28-Feb-00	0.0735	0.0376	0.0321	0.0022
27-Mar-00	0.0093	0.0050	0.0622	0.0032
24-Apr-00	0.0548	0.0206	0.2055	0.0089
15-May-00	0.0161	0.0174	0.0153	0.0024
12-Jun-00	0.0000	0.0000	0.0016	0.0005
10-Jul-00	0.0000	0.0000	0.0000	0.0000
08-Aug-00	0.0000	0.0000	0.0000	0.0000
05-Sep-00	0.0000	0.0000	0.0000	0.0000
02-Oct-00	0.0000	0.0000	0.0000	0.0000
13-Nov-00	0.0000	0.0000	0.0038	0.0008
18-Dec-00	0.0969	0.0584	0.0077	0.0010

Fecundity Hindcast Model (FH)

No independent estimate of survival for northern lampfish between egg to entrainment age was found in the literature, and therefore, *FH* could not be calculated for this taxon.

Adult Equivalent Loss (AEL)

No independent estimate of survival of northern lampfish between age of entrainment and the adult stage was found in the literature, and therefore, *AEL* could not be calculated for this taxon.

Summary

No commercial or recreational fishery for northern lampfish exists in California. Northern lampfish occur from the shoreline out to depths of approximately 3,000 m (9,800 ft) (Miller and Lea 1972). Their ability to actually settle out and mature in nearshore areas such as Morro Bay is unknown and the occurrence of the larvae in the bay may be the result of onshore currents. Once the larvae are in nearshore areas they may be lost as a source of new recruits to the adult population in deeper waters. The *ETM* results show that the power plant may annually entrain approximately 2 percent (*S.E.* 41 to 81) of the northern lampfish larvae from the extrapolated area of inference used in calculating P_s . The primary offshore source of the population for this taxon and the small magnitude of loss (P_m) indicate that entrainment is unlikely to represent any risk to northern lampfish.

5.1.3.4 Shadow goby

Based on the estimate of annual total entrainment of all fish larvae, shadow goby comprised an estimated 2.7 percent of the larvae entrained (Table 5-1). The annual estimate of entrainment for January– December 2000 was 13,503,587 larvae (*S.E.* = 696,629) (Table 5-1).

Empirical Transport Model (ETM)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate the period of entrainment risk for shadow goby larvae. Although Brothers (1975) does not report a larval growth rate for either shadow or arrow goby he estimated that the rate for shadow goby is approximately half that of arrow goby. A growth rate of 0.27 mm/day (0.01 in./day) reported by Steele (1997) for blackeye goby was used in model calculations for the unidentified goby group (primarily arrow goby). Therefore, a growth rate of 0.135 mm/day (0.005 in./day), half the growth rate of blackeye goby, was used to estimate periods of entrainment risk for shadow goby. The range from 2.9 to 4.3 mm (0.11 to 0.17 in.)

was used to estimate a maximum period of entrainment risk of 10.1 days, while the duration to the mean length of 3.5 mm (0.14 in.) was estimated as 4.3 days.

Estimates of P_m for shadow goby ranged from 0.03 (*S.E.* = 0.169) for the average duration of larval exposure (4.3 days) to 0.06 (*S.E.* = 0.240) for the maximum duration of larval exposure (10.1 days). The estimates did not include an adjustment for P_s because this taxon primarily utilizes the bay and estuarine habitats within Morro Bay. The largest fractions of the population were collected during the June (f_i = 0.3764) and September (f_i = 0.2040) surveys (Table 5-8). Proportional entrainment (*PE*) estimates for these two surveys were smaller than *PE* values in February and March when shadow goby larvae were more uniformly distributed among the source water stations inside Morro Bay (Figure 3-22). *PE* estimates ranged from 0.0000 to 0.0466 (Table 5-8). During the later summer months the larvae were in much greater abundance at the stations in the interior areas of Morro Bay; the preferred habitat for adult shadow goby (Figure 3-22).

Table 5-8. *ETM* data for shadow goby *Quietula y-cauda*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0000	0.0000	0.0000	0.0000
28-Feb-00	0.0466	0.0151	0.0223	0.0028
27-Mar-00	0.0445	0.0376	0.0372	0.0048
24-Apr-00	0.0113	0.0032	0.0743	0.0055
15-May-00	0.0146	0.0018	0.0976	0.0069
12-Jun-00	0.0026	0.0011	0.3764	0.0284
10-Jul-00	0.0016	0.0007	0.0972	0.0066
08-Aug-00	0.0067	0.0016	0.0707	0.0064
05-Sep-00	0.0011	0.0008	0.2040	0.0240
02-Oct-00	0.0000	0.0000	0.0162	0.0017
13-Nov-00	0.0000	0.0000	0.0041	0.0013
18-Dec-00	0.0000	0.0000	0.0000	0.0000

Fecundity Hindcast Model (*FH*)

The parameters required for formulation of the *FH* estimate for shadow goby were collected from Brothers (1975). Egg survival was assumed to be 100 percent because egg masses in gobies are demersal and attached to the substrate (Wang 1986) and parental care is common in the family (Moser 1996). Although no estimate of larval survival is available, Brothers (1975) estimates that 99.2 percent larval mortality occurs over the two month period of larval development. Daily survival was therefore estimated as $(1\text{-}0.992)^{6\,/\,365.25} = 0.923^{d\text{-}1}$ (the value for survival was estimated using an exponent of 6/365.25 because there are six two-month periods within a year).

Survival to entrainment was then estimated using the mean number of days to entrainment (4.3 days) as $0.923^{4.25} = 0.71$. A batch fecundity estimate of 1,000 eggs was used based on data presented in Brothers (1975). Brothers (1975) reports that gobies may spawn multiple times during the year, so an estimate of two spawns per year was used in calculating *FH* (1,000 eggs/spawn x 2 spawns/year = 2,000 eggs). Shadow goby live longer than arrow goby and longevity and age at maturity values of 4.5 years and 1.5 years, respectively, were used in the model (Brothers 1975). The number of adult females hindcast was 6,339 (90 percent C.I. = 2,217 to 18,119) (Table 5-9).

Table 5-9. Annual estimates of female adult shadow goby losses based on larval entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	6,339	4,047	18,119	2,217	15,902
Entrainment	13,503,587	696,629	6,877	5,801	1,076
Larval survival	0.7101	0.2130	10,383	4,501	5,882
# Eggs/year	2,000	600	10,383	3,870	6,513
Longevity	4.5	1.35	15,247	3,239	12,008
Maturation	1.5	0.45	9,308	5,305	4,003

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and larval survivorship, in that order (Table 5-9).

Adult Equivalent Loss (AEL)

The parameters required for formulation of *AEL* estimates for shadow goby include larval survival from entrainment to settlement and survival from settlement to age 3.0 years, the average age of the adults between ages 1.5 and 4.5 years. Larval survival from entrainment to settlement (60 days) was estimated as $0.923^{60-4.25} = 0.0113$ using the same daily survival rate used in formulating *FH*. Brothers (1975) estimated an annual mortality rate following settlement of 0.62 - 0.69. Therefore, the daily survival rate was estimated as $0.997 = (1-0.655)^{(1/365.25)}$, and survival from settlement through age 3.0 years was estimated as 0.049. The estimated number of equivalent adults corresponding to the number of larvae that would have been entrained by the proposed MBPP combined-cycle intake was 7,436 (90 percent C.I. = 3,681 to 15,020) (Table 5-10).

Table 5-10. Annual estimates of adult shadow goby losses due to entrainment using Adult Equivalent Loss model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *AEL*	Lower Estimate of *AEL*	*AEL* Range
Adult Equivalents	7,436	3,178	15,020	3,681	11,339
Total Entrainment	13,503,587	696,629	8,067	6,805	1,262
Early Larval Survival	0.0113	0.0034	12,180	4,539	7,641
Pre-Recruit Survival	0.0489	0.0147	12,180	4,539	7,641

Summary

Shadow goby have no commercial or recreational fishery value, and there is little information on their ecological role in the community. There are also no fishery data that can be used to compare harvest mortality rates to entrainment mortality rates and provide a context for the model results. Estimates of P_m indicate that the power plant may annually entrain from approximately 3 percent (*S.E.* = 17) to 6 percent (*S.E.* = 24) of the shadow goby larvae from the MBPP source water. This low level of incremental mortality would not be expected to cause any long-term effects on the population. The comparison of densities at the different source water stations over time also indicated that the larvae are more abundant in the adult habitats in the interior of the bay and, based on the short period of time that they are subject to entrainment, likely settle out in these preferred habitats (Figure 3-22).

5.1.3.5 Combtooth blennies

Based on the estimate of annual total entrainment of all fish larvae, combtooth blennies comprised an estimated 2.0 percent of the larvae entrained (Table 5-1). The annual estimate of entrainment for January – December 2000 was 10,042,151 larvae (*S.E.* = 231,612) (Table 5-1).

Empirical Transport Model (ETM)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate the duration of entrainment risk for combtooth blenny larvae. The growth rate for combtooth blenny larvae was estimated by averaging the growth rates of three sympatric blennioids (0.117, 0.190, 0.103 mm/day [0.005, 0.007, 0.004 in./day] from Stephens et al. (1970). This average growth rate was used to convert length frequency analysis results to estimate the duration of entrainment exposure. The range from 2.0 to 3.1 mm (0.08 to 0.12 in.) was used to estimate a maximum period of entrainment risk of 8.1 days, while the duration to the mean length of 2.5 mm (0.098 in.) was estimated as 4.0 days.

Estimated P_m values for combtooth blennies ranged from 0.49 (*S.E.* = 0.60) for the average duration of larval exposure (4.0 days) to 0.72 (*S.E* = 0.59) for the maximum duration of larval exposure (8.1 days). The model estimates did not include an adjustment for P_s because this taxon primarily utilizes the bay and estuarine habitats within Morro Bay. *PE* estimates ranged from 0.0000 to 0.1996 (Table 5-11). The largest fractions of the population were collected during the July, August, and September surveys (f_i = 0.2457, f_i = 0.3702, and f_i = 0.2241, respectively) (Table 5-11). The relatively large *PE* estimates for these surveys contributed to the large values of P_m for this taxon.

Table 5-11. *ETM* data for combtooth blennies *Hypsoblennius* spp. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0000	0.0000	0.0021	0.0007
28-Feb-00	0.0000	0.0000	0.0069	0.0013
27-Mar-00	0.1996	0.1489	0.0031	0.0009
24-Apr-00	0.0000	0.0000	0.0023	0.0008
15-May-00	0.1077	0.1266	0.0048	0.0006
12-Jun-00	0.1195	0.0309	0.0266	0.0029
10-Jul-00	0.1826	0.0440	0.2457	0.0095
08-Aug-00	0.1884	0.0702	0.3702	0.0112
05-Sep-00	0.1486	0.0248	0.2241	0.0107
02-Oct-00	0.0753	0.0656	0.0832	0.0055
13-Nov-00	0.0000	0.0000	0.0273	0.0037
18-Dec-00	0.0000	0.0000	0.0038	0.0005

Fecundity Hindcast Model (FH)

The total annual larval entrainment for combtooth blennies was used to estimate the number of breeding females needed to produce the number of larvae entrained (Table 5-1). The parameters required for formulation of *FH* estimates for combtooth blennies were compiled primarily from Stephens et al. (1970) studies on three sympatric species of blennies. Stephens et al. (1970) do not report estimates of egg survival. The egg masses are demersal and attached to a nest site that is guarded by the male (Stephens et al. 1970). Therefore, egg survival is probably high and assumed to be 100 percent. Although no estimate of larval survival is available, Brothers (1975) indicates that 98.3 percent larval mortality over two months was a reasonable estimate for arrow gobies. We assumed 99 percent larval mortality for combtooth blennies that occupy similar habitats. This estimate was used to calculate a daily survival rate for the estimated total larval duration of two to three months (Stephens et al. 1970) ($(1\text{-}0.99)^{1/75} = 0.940^{d\text{-}1}$). Survival to entrainment was then estimated using the mean number of days to entrainment (4.03 days) as $0.940^{4.03} = 0.78$. A fecundity estimate of 1,180 eggs was used based on the estimates for

H. jenkinsi in Stephens et al. (1970), assuming that the maximum egg production of 1,500 after three years occurs over the remaining average maximum lifespan of seven years. The average age of maturity was assumed to be two years. The number of adult females hindcast from the larvae entrained at the MBPP was 4,361 (90 percent C.I. = 1,601 to 11,884) (Table 5-12).

Table 5-12. Annual estimates of female adult combtooth blenny losses based on larval entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	4,361	2,658	11,884	1,601	10,283
Entrainment	10,042,151	231,612	4,527	4,196	331
Larval survival	0.7805	0.2342	7,144	3,404	3,740
# Eggs/year	1,180	354	7,144	2,663	4,481
Longevity	7.0	2.1	9,592	2,304	7,288
Maturation	2.0	0.6	5,856	3,773	2,083

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and larval survivorship, in that order (Table 5-12).

Adult Equivalent Loss (AEL)

The parameters required for formulation of *AEL* estimates for combtooth blennies include larval survival from entrainment to settlement and survival from settlement to age 4.5 years, the average age of the mature adults used in calculating *FH*. Larval survival from entrainment to settlement (75 days) was estimated as $0.94^{75-4.0} = 0.01$ using the same daily survival rate used in formulating *FH*. Adult mortality was estimated from age groupings of three species of blennies in Stephens et al. (1970).

Exponential instantaneous mortality rates (Z) were calculated from these age groupings using the relationship between log numbers at age $\ln(N_t)$ and age t:

$$\ln(N_t) = -Zt + b.$$

The average of the 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 at 0.525 yr^{-1}. Using this annual rate, the survival from settlement to age 4.5 years was estimated as 0.063. The estimated number of equivalent adults corresponding to the number of larvae that would have been entrained by the proposed MBPP combined-cycle intake was 8,084 (90 percent C.I. = 4,019 to 16,262)

(Table 5-13). The uncertainty of our *AEL* estimate is most affected by the model parameters of early larval and early juvenile survivorship.

Table 5-13. Annual estimates of female adult combtooth blennies losses due to entrainment using Adult Equivalent model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *AEL*	Lower Estimate of *AEL*	*AEL* Range
Adult Equivalents	8,084	3,435	16,262	4,019	12,243
Total Entrainment	10,042,151	231,612	8,391	7,777	614
Early Larval Survival	0.0128	0.0038	13,242	4,935	8,307
Pre-Recruit Survival	0.0628	0.0188	13,242	4,935	8,307

Summary

The species of larval combtooth blenny in our study area and entrainment samples has not been positively identified (Section 3.2.3). 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.

Estimates of P_m indicate that the power plant may annually entrain an average of 49 percent (*S.E.* = 60) to a maximum of 72 percent (*S.E.* = 59) of the combtooth blenny larvae from the MBPP source water. It is unknown what effect this high level of incremental mortality has on the local population. The comparison of densities at the different source water stations over time indicated that the larvae were more abundant at the intake station than they were at the other stations in the bay (Figure 3-26). This is also shown in the small size of the entrained larvae, indicating that they were close to hatch size and the adult source population. The preferred habitat for combtooth blennies is pier pilings and the associated fouling communities that are most common in the part of the bay nearest the intake station. This has possibly resulted in the high P_m estimate for this taxa group. The only context for the P_m estimates are the *FH* and *AEL* results that showed that the incremental mortality due to entrainment may be equivalent to the loss of 4,361 (*S.E.* = 2,658) adult females or 8,084 (*S.E.* = 3,435) adults. The results closely match the relationship of $2FH \equiv AEL$ because *AEL* was calculated to the same average age of the adults used in calculating *FH* (4.5 years).

5.1.3.6 Kelp, Gopher, and Black-and-Yellow Rockfish Complex

Based on the estimate of annual total entrainment of all fish larvae, the kelp, gopher, and black-and-yellow rockfish complex (KGB) comprised an estimated 1.3 percent of the larvae entrained (Table 5-1). The annual estimate of entrained larvae for January – December 2000 was 6,406,622 larvae (*S.E.* = 188,985) (Table 5-1).

Empirical Transport Model (ETM)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate the period of entrainment risk for KGB rockfish complex larvae. An estimate of the growth rate for KGB rockfish was not available from the literature, so a growth rate from larval brown rockfish of 0.14 mm/day (0.006 in./day) (Love and Johnson 1999, Yoklavich et al. 1996) was used to convert length frequency analysis results to estimate the duration of entrainment exposure. The range from 3.5 to 5.1 mm (0.14 to 0.20 in.) was used to estimate a maximum of 11.3 days, while the duration to the mean length of 4.3 mm (0.17 in.) was estimated as 5.5 days.

The estimated P_m value for the KGB rockfish complex was 0.02 (*S.E.* = 0.371 to a maximum of 0.537) for the period of entrainment risk applied in the model (5.5 and 11.3 days). The model included an adjustment for P_s because this taxon occupies nearshore habitats that extend well beyond the sampling areas. *PE* estimates ranged from 0.0000 to 0.3097 (Table 5-14). The largest fraction of the population was collected during the April (f_i = 0.6811) survey (Table 5-14).

Table 5-14. *ETM* data for KGB rockfish *Sebastes* spp. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.3097	0.4379	0.0040	0.0013
28-Feb-00	0.0509	0.0593	0.0308	0.0043
27-Mar-00	0.0000	0.0000	0.0849	0.0048
24-Apr-00	0.0295	0.0190	0.6811	0.0122
15-May-00	0.0208	0.0066	0.0847	0.0069
12-Jun-00	0.0000	0.0000	0.1145	0.0084
10-Jul-00	0.0000	0.0000	0.0000	0.0000
08-Aug-00	0.0000	0.0000	0.0000	0.0000
05-Sep-00	0.0000	0.0000	0.0000	0.0000
02-Oct-00	0.0000	0.0000	0.0000	0.0000
13-Nov-00	0.0000	0.0000	0.0000	0.0000
18-Dec-00	0.0000	0.0000	0.0000	0.0000

Fecundity Hindcast Model (FH)

The total annual larval entrainment for KGB rockfish was used to estimate the number of breeding females needed to produce the number of larvae entrained (Table 5-1). The parameters required for formulation of *FH* estimates for KGB rockfishes were compiled from references on different rockfish species. Rockfishes are viviparous and release larvae once per year. Survival of the larvae from time of release to entrainment was estimated using an instantaneous mortality rate of 0.14/day from blue rockfish (Mary Yoklavich, NOAA/NMFS/PFEG, Pacific Grove, CA, pers. comm. 1999) over 5.5 days ($e^{(-0.14*5.5)} = 0.46$). An average annual fecundity estimate of 213,000 eggs per female was used in calculating *FH* (DeLacy 1964: 52,000-339,000; MacGregor 1970: 44,118-104,101 and 143,156-182,890; Love and Johnson 1999: 80,000-760,000). Estimates of five years as the age at maturity and 15 years for longevity were used in calculating *FH* (Burge and Schultz 1973, Wyllie Echeverria 1987, Lea et al. 1999). The number of adult females hindcast from the larvae entrained at the MBPP was 13 (90 percent C.I. = 5 to 37) (Table 5-15).

Table 5-15. Annual estimates of female KGB rockfish losses based on larval entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	13	8	37	5	32
Entrainment	6,406,622	188,985	14	12	2
larval survival	0.4601	0.1380	21	8	13
# Eggs/year	213,000	63,900	21	8	13
Longevity	15.0	4.5	31	7	24
Maturation	5.0	1.5	19	11	8

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and larval survivorship, in that order (Table 5-15).

Adult Equivalent Loss (AEL)

The total annual MBPP entrainment of KGB rockfish (January – December 2000) was used to estimate the number of equivalent adults theoretically lost to the population. The parameters required for formulation of *AEL* estimates for KGB rockfish were derived from data on larval blue rockfish survival. Survivorship of KGB rockfishes from parturition to an estimated recruitment age of three years was partitioned into six stages (Table 5-16). *AEL* was calculated assuming the entrainment of a single age class having the average age of recruitment. The estimated number of equivalent adults corresponding to the number of larvae that would have been entrained by the proposed MBPP combined-cycle intake was 23 (90 percent C.I. = 8 to 69)

(Table 5-16). The uncertainty of our *AEL* estimate is most affected by the model parameters of early larval and early juvenile survivorship. No independent estimate of survival of KGB rockfishes between age of entrainment and adult stage was found in the literature.

Table 5-16. Three-year survival for the KGB rockfish complex larvae (*Sebastes* spp. V_De/V_D_), based on blue rockfish *Sebastes mystinus* data.

Lifestage	Day (Start)	Day (End)	Instantaneous Natural Mortality (*Z*)	Survival (*S*)
Larval survival	0	5.5	0.14	0.46
Early larval	5.5	20	0.14	0.13
Late larval	20	60	0.08	0.04
Early juvenile	60	180	0.04	0.01
Late juvenile	180	365	0.0112	0.13
Pre-recruit	365	1,095	0.0006	0.65

Note: Survival was estimated from release as $S = e^{(-Z)(\mathrm{Day(end)}-\mathrm{Day(Start)})}$. Daily instantaneous mortality rates (*Z*) for blue rockfish larvae were used to calculate KGB larval survivorship and were provided by Mary Yoklavich (NOAA/NMFS/PFEG, Pacific Grove, CA, pers. comm. 1999). Annual instantaneous mortality was assumed as 0.2/year after two year average age of entrainment was estimated as 5.5 days based on average size at entrainment and a growth rate of 0.14 mm/day (0.006 in./day) (Yoklavich et al. 1996).

Table 5-17. Annual estimates of adult KGB rockfish losses due to entrainment using Adult Equivalent model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *AEL*	Lower Estimate of *AEL*	*AEL* Range
Adult equivalents	23	15	69	8	61
Total Entrainment	6,406,622	188,985	24	22	2
Early Larval Survival	0.1313	0.0394	38	14	24
Late Larval Survival	0.0408	0.0122	38	14	24
Early Juvenile Survival	0.0082	0.0025	38	14	24
Juvenile Survival	0.1259	0.0378	38	14	24
Pre-recruit Survival	0.6453	0.1936	36	14	22

Summary

KGB rockfish are an important component of the local recreational and commercial fishing industries. The P_m estimates for this taxa group indicate an incremental loss to the local larval population due to entrainment of approximately 2 percent (*S.E.* = 41 to 82). The estimate of P_m and the estimates from the *FH* and *AEL* models indicate very little risk to the local population due to entrainment. The *FH* and *AEL* estimates are very close using the relationship of $2FH \equiv AEL$, providing additional assurance for our assessment of low impacts for this taxa group.

5.1.3.7 Jacksmelt

Based on the estimate of annual total entrainment of all fish larvae, jacksmelt comprised an estimated 1.2 percent of the larvae entrained (Table 5-1). The annual estimate of entrainment for January – December 2000 was 6,266,107 larvae (*S.E.* = 284,014) (Table 5-1).

Empirical Transport Model (ETM)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate the period of entrainment risk for jacksmelt larvae. Middaugh et al. (1990) found hatching size to range from 7.9 to 8.1 mm (0.31 to 0.32 in.) and the size at 24 days to range from 15.1 to 17.6 mm (0.6 to 0.7 in.). These values were used to calculate an estimated daily growth rate of 0.348 mm (0.014 in.) which was used to convert length frequency analysis results to estimate the duration of entrainment exposure. The range from 6.2 to 14.9 mm (0.24 to 0.59 in.) was used to estimate a maximum period of entrainment risk of 24.8 days, while the duration to the mean length of 9.6 mm (0.38 in.) was estimated as 9.7 days.

Estimates of P_m for jacksmelt ranged from 0.22 (*S.E.* = 0.43) for the duration to the average larval size at entrainment (9.7 days), to 0.44 (*S.E.* = 0.55) for the duration to the maximum larval size at entrainment (24.8 days). The model estimates did not include an adjustment for P_s because this taxon primarily utilizes the bay and estuarine habitats within Morro Bay for spawning. *PE* estimates ranged from 0.0000 to 0.2295 (Table 5-18). The largest fraction of the population was collected during the January (f_i = 0.4337) and February (f_i = 0.3382) surveys (Table 5-18).

Table 5-18. *ETM* data for jacksmelt *Atherinopsis californiensis*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0206	0.0158	0.4337	0.0240
28-Feb-00	0.0185	0.0050	0.3382	0.0197
27-Mar-00	0.0733	0.0405	0.1236	0.0167
24-Apr-00	0.0575	0.0644	0.0341	0.0052
15-May-00	0.0000	0.0000	0.0025	0.0014
12-Jun-00	0.0000	0.0000	0.0023	0.0009
10-Jul-00	0.0000	0.0000	0.0030	0.0011
08-Aug-00	0.2295	0.2817	0.0023	0.0010
05-Sep-00	0.0000	0.0000	0.0009	0.0007
02-Oct-00	0.0000	0.0000	0.0000	0.0000
13-Nov-00	0.0109	0.0088	0.0150	0.0022
18-Dec-00	0.0046	0.0046	0.0446	0.0038

Fecundity Hindcast Model (FH)

No independent estimate of survival for jacksmelt between egg to entrainment age was found in the literature, and therefore, *FH* could not be calculated for this taxon.

Adult Equivalent Loss (AEL)

No independent estimate of survival of jacksmelt between age of entrainment and the adult stage was found in the literature, and therefore, *AEL* could not be calculated for this taxon.

Summary

No commercial or recreational fishery for jacksmelt exists in Morro Bay, although they are probably taken for use as bait fish. There are also no local fishery data that can be used to compare harvest mortality rates to entrainment mortality rates and provide some context for the *ETM* results. Although P_m indicates that the power plant may annually entrain up to 44 percent (*S.E.* = 55) of the jacksmelt larvae from the MBPP source water, there are no independent population estimates that would help determine if this loss has resulted in any long-term effects on the local population.

5.1.3.8 White Croaker

Based on the estimate of annual total entrainment of all fish larvae, white croaker comprised an estimated 0.6 percent of the larvae entrained (Table 5-1). The annual estimate of entrainment for January – December 2000 was 2,992,511 larvae (*S.E.* = 116,314) (Table 5-1).

Empirical Transport Model (ETM)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate period of entrainment risk for white croaker larvae. A growth rate of 0.20 mm/day (0.008 in./day) (Murdoch et al. 1989) was used to convert length frequency analysis results to estimate the duration of entrainment exposure. The range from 1.4 to 6.1 mm (0.06 to 0.24 in.) was used to estimate a maximum period of entrainment risk of 23.5 days, while the duration to the mean length of 2.8 mm (0.11 in.) was estimated as 6.9 days.

The estimate of P_m for white croaker was 0.02 (*S.E.* = 0.39 to 0.73) for the period of entrainment exposure applied in the model (6.9 and 23.5 days). The model included an adjustment for P_s because this taxon occupies nearshore and offshore habitats that extend well beyond the sampling areas. White croaker spawn multiple times and as a result their larvae were collected throughout the year in entrainment samples (Table 5-19). The largest fraction of the population was collected during the February survey (f_i = 0.3827) (Table 5-19). Similar to the results for Pacific herring, the peak entrainment abundances in February did not occur when source water stations were sampled and, as a result, no *PE* estimate was calculated for that month. *PE* estimates ranged from 0.0000 to 0.0879 (Table 5-19).

Table 5-19. *ETM* data for white croaker *Genyonemus lineatus*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0000	0.0000	0.0535	0.0059
28-Feb-00	0.0000	0.0000	0.3827	0.0200
27-Mar-00	0.0879	0.0355	0.0691	0.0112
24-Apr-00	0.0233	0.0244	0.1676	0.0177
15-May-00	0.0000	0.0000	0.0024	0.0014
12-Jun-00	0.0000	0.0000	0.0000	0.0000
10-Jul-00	0.0000	0.0000	0.0064	0.0024
08-Aug-00	0.0000	0.0000	0.0000	0.0000
05-Sep-00	0.0529	0.0605	0.0394	0.0073
02-Oct-00	0.0116	0.0117	0.0050	0.0020
13-Nov-00	0.0639	0.0401	0.1584	0.0152
18-Dec-00	0.0000	0.0000	0.1156	0.0100

Fecundity Hindcast Model (FH)

The total annual larval entrainment for white croaker was used to estimate the number of breeding females needed to produce the number of larvae entrained (Table 5-1). White croaker spawn from 18 times per year for females of one to two years to 24 times for older females (Love et al. 1984). In our calculations for *FH* we used an average of 21 egg batches per year. A batch fecundity of 5,000 eggs was extrapolated from Love et al. (1984) resulting in a total annual fecundity of 105,000 eggs. Love (1996) reported that white croaker eggs hatch in about two days, while Murdoch et al. (1989) suggested a daily instantaneous egg mortality rate of Z = 0.25 (survival=78 percent per day). Egg survival was therefore estimated as $e^{(0.25*-2)} = 0.61$. The same instantaneous mortality rate was used to calculate larval survival from hatching to entrainment at 6.9 days based on the mean entrainment length ($e^{(0.25*-6.9)} = 0.18$). An estimate of longevity of 12 years from Love et al. (1984) was used in the model, and the average age of maturation was estimated to be two years based on Love's (1996) estimate that the species matures from one to four years with approximately half of the females spawning after one year. The number of adult females hindcast from the larvae entrained at the MBPP was 53 (90 percent C.I. = 21 to 133) (Table 5-20).

Table 5-20. Annual estimates of female white croaker losses based on larval entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	53	30	133	21	112
Entrainment	2,992,511	116,314	56	50	6
Egg Survival	0.6065	0.0000	53	53	0
Larval survival	0.1775	0.0532	87	32	55
# Eggs/year	105,000	31,500	87	32	55
Longevity	12.0	3.6	99	30	69
Maturation	2.0	0.6	61	49	12

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and survivorship (Table 5-20).

Adult Equivalent Loss (AEL)

No independent estimate of white croaker survival between the age of entrainment and the adult stage was available so *AEL* model estimates could not be calculated.

Summary

There is no local commercial fishery for white croaker, although they are commonly taken in the recreational fishery. Results from the *ETM* and *FH* modeling indicated a potential for minimal effects on white croaker. In addition, P_m overestimates entrainment effects because of the absence of larval white croaker in source water sampling during the period of highest entrainment abundance.

5.1.3.9 Pacific Herring

Based on the estimate of annual total entrainment of all fish larvae, Pacific herring comprised an estimated 0.6 percent of the larvae entrained (Table 5-1). The annual estimate of entrainment for January – December 2000 was 3,030,431 larvae (*S.E.* = 51,487) (Table 5-1).

Empirical Transport Model (ETM)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate the period of entrainment risk for Pacific herring larvae. The larval growth rate used in calculating the period of entrainment risk was estimated by averaging transformation and hatch lengths from Moser (1996), and using 70 days as the period to transformation (Wang 1986). The calculation was as follows: (average(25,27,35)-average(5.6,7.5)) / 70 = 0.32 mm/d. This value was used to convert length frequency analysis results to estimate the duration of entrainment exposure. The range from 4.8 to 8.9 mm (0.19 to 0.35 in.) was used to estimate a maximum period of entrainment risk of 13.0 days, while the duration to the mean length of 7.1 mm (0.28 in.) was estimated as 7.3 days.

Estimates of P_m for Pacific herring ranged from 0.01 (*S.E.* = 0.09) for the duration to the average larval size at entrainment (7.3 days), to 0.02 (*S.E.* = 0.11) for the duration to the maximum larval size at entrainment (13.0 days). The model estimates did not include an adjustment for P_s because this taxon primarily utilizes the bay and estuarine habitats within Morro Bay for spawning. *PE* estimates ranged from 0.0000 to 0.0653 (Table 5-21). The largest fraction of the population was collected during the December survey (f_i = 0.9005) (Table 5-21). Most of the herring larvae were taken during entrainment surveys that were not paired with source water collections and, as a result, no *PE* estimates were calculated for those months.

Table 5-21. *ETM* data for Pacific herring *Clupea pallasi*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0653	0.0542	0.0301	0.0060
28-Feb-00	0.0000	0.0000	0.0572	0.0097
27-Mar-00	0.0000	0.0000	0.0060	0.0023
24-Apr-00	0.0000	0.0000	0.0061	0.0023
15-May-00	0.0000	0.0000	0.0000	0.0000
12-Jun-00	0.0000	0.0000	0.0000	0.0000
10-Jul-00	0.0000	0.0000	0.0000	0.0000
08-Aug-00	0.0000	0.0000	0.0000	0.0000
05-Sep-00	0.0000	0.0000	0.0000	0.0000
02-Oct-00	0.0000	0.0000	0.0000	0.0000
13-Nov-00	0.0000	0.0000	0.0000	0.0000
18-Dec-00	0.0000	0.0000	0.9005	0.0112

Fecundity Hindcast Model (FH)

The total annual larval entrainment for Pacific herring was used to estimate the number of breeding females needed to produce the number of larvae entrained (Table 5-1). The parameters required for formulation of *FH* estimates for Pacific herring were available from the literature as herring are an important commercial species and have been extensively studied. Pacific herring spawn once per season and produce from 4,000 to 130,000 eggs (Wang 1986). Therefore, the midpoint between the estimates (67,000) was used as the estimate of the average annual fecundity. Egg mortality has been estimated to range from 20 percent (Hourston and Haegle 1980) to as high as 99 percent (Hardwick 1973, Leet et al. 1992). Egg survival was estimated from these values as 0.40 = (1-(0.99 + 0.20) / 2). Larval mortality is also high and an assumed to be 99 percent from hatching until metamorphosis at 70 days (Hay 1985). Survival of the larvae from time of hatching to entrainment was therefore estimated using a daily survival rate $(1\text{-}0.99)^{1/70} = 0.936^{d\text{-}1}$. Survival to entrainment was then estimated using the mean number of days to entrainment (7.33 days) as $0.936^{7.33} = 0.62$. Fitch and Lavenberg's (1975) estimate for longevity of 11 years and an average age of maturity of 2.5 years of age (based on Love's (1996) age of maturity estimate of two to three years) were used in calculating total fecundity for the model. The number of adult females hindcast from the larvae entrained at MBPP was 43 (90 percent C.I. = 15 to 127) (Table 5-22).

Table 5-22. Annual estimates of female Pacific herring losses based on larval entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	43	28	127	15	112
Entrainment	3,030,431	51,487	44	42	2
Egg survival	0.4000	0.1200	71	26	45
Larval survival	0.6174	0.1852	71	27	44
# Eggs/year	67,000	20,100	71	26	45
Longevity	11.0	3.3	87	24	63
Maturation	2.5	0.8	53	39	14

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and survivorship (Table 5-22).

Adult Equivalent Loss (AEL)

The total annual MBPP entrainment of Pacific herring (January – December 2000) was used to estimate the number of equivalent adults theoretically lost to the population. The parameters required for formulation of *AEL* estimates for Pacific herring were available from the literature. Survivorship of Pacific herring larvae from entrainment to estimated settlement age of 70 days (Hay 1985) was estimated using the same daily survival rate used in calculating *FH* ($(1\text{-}0.99)^{1/70} = 0.936^{d\text{-}1}$). Survival from settlement to the average age of mature adults used in *FH* (6.75 years) was estimated using an adult mortality rate of 50 percent ($Z = 0.69$) (Hourston and Haegele 1980). The estimated number of equivalent adults corresponding to the number of larvae that would have been entrained by the proposed MBPP combined-cycle intake was 532 (90 percent C.I. = 264 to 1,069) (Table 5-23).

Table 5-23. Annual estimates of adult Pacific herring losses due to entrainment using Adult Equivalent model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *AEL*	Lower Estimate of *AEL*	*AEL* Range
Adult Equivalents	532	226	1,069	264	805
Total Entrainment	3,030,431	51,487	547	517	30
Early Larval Survival	0.0162	0.0049	871	325	546
Pre-recruit Survival	0.0108	0.0032	871	325	546

Summary

There is no local fishery for Pacific herring. Results from all three modeling approaches indicated the potential for very minimal effects on Pacific herring. Although P_m probably underestimates entrainment effects because of the absence of source water sampling during the period of highest entrainment abundance, the results from the *FH* and *AEL* models provided some assurance that entrainment effects on the adult population would be low.

5.1.3.10 Cabezon

Based on the estimate of annual total entrainment of all fish larvae, cabezon comprised an estimated 0.6 percent of the larvae entrained (Table 5-1). The annual estimate of entrainment for January – December 2000 was 2,888,498 larvae (*S.E.* = 137,151) (Table 5-1).

Empirical Transport Model (ETM)

The mean, maximum, and minimum values from the length frequency data that were presented in Section 3.0 were used to estimate period of entrainment risk for cabezon larvae. A larval growth rate of 0.3 mm/day (0.01 in./day) derived from O'Connell (1953) and Moser (1996) was used to convert length frequency analysis results to estimate the duration of entrainment exposure. The range from 3.5 to 6.7 mm (0.14 to 0.26 in.) was used to estimate a maximum period of entrainment risk of 10.8 days, while the duration to the mean length of 5.3 mm (0.21 in.) was estimated as 5.9 days.

The P_m estimate for cabezon was 0.04 (*S.E.* = 0.47 to 0.63) for the period of entrainment risk applied in the model (5.9 and 10.8 days). The model included an adjustment for P_s because this taxon occupies nearshore habitats that extend well beyond the sampling areas. Cabezon spawn in the early winter and as a result their larvae were present in source water surveys at the start and end of the annual period used for analysis (Table 5-24). Therefore, the samples represented the reproductive output from portions of two different seasons. The actual timing of reproduction in either of these two seasons would affect whether P_m is representative. *PE* estimates ranged from 0.0000 to 0.1361 (Table 5-24). The largest fraction of the population was collected during the February survey (f_i = 0.5023) (Table 5-24).

Table 5-24. *ETM* data for cabezon *Scorpaenichthys marmoratus*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0259	0.0291	0.1342	0.0092
28-Feb-00	0.0105	0.0074	0.5023	0.0241
27-Mar-00	0.1361	0.0763	0.0872	0.0118
24-Apr-00	0.0000	0.0000	0.0227	0.0044
15-May-00	0.0000	0.0000	0.0000	0.0000
12-Jun-00	0.0000	0.0000	0.0000	0.0000
10-Jul-00	0.0000	0.0000	0.0000	0.0000
08-Aug-00	0.0000	0.0000	0.0000	0.0000
05-Sep-00	0.0000	0.0000	0.0000	0.0000
02-Oct-00	0.0358	0.0395	0.0031	0.0016
13-Nov-00	0.1088	0.0479	0.0711	0.0091
18-Dec-00	0.0568	0.0211	0.1794	0.0136

Fecundity Hindcast Model (FH)

No independent estimate of larval cabezon survival to entrainment age was found in the literature so *FH* could not be calculated.

Adult Equivalent Loss (AEL)

No independent estimate of survival of cabezon between age of entrainment and adult stage was found in the literature so *AEL* was not calculated.

Summary

There is a large valuable local commercial fishery for cabezon, and it is also an important component of the local recreational fishery. The P_m estimate for cabezon indicate a low potential for any impact to this taxon due to entrainment.

5.1.3.11 Brown Rock Crab

The brown rock crab comprised 71.8 percent of all entrained cancer crab megalopae (Table 5-2). The annual estimate of entrainment for January – December 2000 was 9,744,688 (*S.E.* = 224,772) (Table 5-2).

Brown rock crabs are an important commercial and recreational species. Larval development in the brown rock crab was described by Roesijadi (1976). Eggs hatch into pre-zoea larvae that molt to first stage zoea in less than one hour. Average larval development time (from hatching through completion of the fifth stage) was 36 days at 13.8 °C (56.8 °F). Although some crabs molted to the megalopal stage, none molted to the first crab instar stage, so the actual duration of the megalopal stage is unknown. A reasonable estimate can be derived from studies of slender crab where the average duration of the megalopal stage was found to be 14 days (Ally 1975).

Empirical Transport Model (ETM)

The P_m estimate for brown rock crab was 0.03 (*S.E.* = 1.22) based on a period of entrainment risk of 43.3 days, half of the average megalopal stage duration including the cumulative average zoeal stage durations (Ally 1975). The model included an adjustment for P_s because this taxon occupies nearshore habitats that extend well beyond the sampling areas. The largest fraction of the population was collected during the June survey (f_i = 0.8331) (Table 5-25). *PE* estimates ranged from 0.0000 to 0.0337 (Table 5-25).

Table 5-25. *ETM* data for brown rock crab *Cancer antennarius*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0000	0.0000	0.0067	0.0002
28-Feb-00	0.0000	0.0000	0.0000	0.0000
27-Mar-00	0.0000	0.0000	0.0000	0.0000
24-Apr-00	0.0001	0.0000	0.0154	0.0017
15-May-00	0.0003	0.0002	0.0664	0.0041
12-Jun-00	0.0337	0.0159	0.8331	0.0076
10-Jul-00	0.0000	0.0000	0.0522	0.0059
08-Aug-00	0.0000	0.0000	0.0015	0.0006
05-Sep-00	0.0000	0.0000	0.0000	0.0000
02-Oct-00	0.0000	0.0000	0.0000	0.0000
13-Nov-00	0.0110	0.0114	0.0023	0.0007
18-Dec-00	0.0000	0.0000	0.0224	0.0028

Fecundity Hindcast Model (FH)

The total annual larval entrainment for brown rock crab was used to estimate the number of breeding females needed to produce the number of megalopae entrained (Table 5-2). The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalopae was calculated assuming an age at maturation of 1.5 years and an average lifespan of 5.5 years (Table 5-26). The number of adult females hindcast from the megalopae entrained at the MBPP combined-cycle intake was 2,596 (90 percent C.I. = 963 to 6,997) (Table 5-26).

Table 5-26. Annual estimates of female brown rock crab losses based on megalopal entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	2,596	1,565	6,997	963	6,034
Entrainment	9,744,688	224,772	2,694	2,497	197
Megalopal survival	0.0011	0.0003	4,252	1,585	2,667
# Eggs/year	1,756,450	526,935	4,252	1,585	2,667
Longevity	5.5	1.65	5,590	1,383	4,207
Maturation	1.5	0.45	3,412	2,265	1,147

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and survivorship (Table 5-26).

Adult Equivalent Loss (AEL)

No independent estimate of survival of brown rock crab between age of entrainment and adult stage was found in the literature so *AEL* could not be calculated.

Summary

Brown rock crab are the major component of the local rock crab fishery that includes several other species. The P_m estimate (3 percent) indicates a low potential for effects on the brown rock crab population. Brown rock crab megalopae can become widely distributed in nearshore waters (Graham 1989). Their occurrence in Morro Bay intake samples are probably the result of onshore water movements as evidenced by their greater abundances at the station in Estero Bay (Figure 3-49). The results from the *FH* model indicated that the annual entrainment represented the loss of approximately 2,600 adult female brown rock crabs.

5.1.3.12 Hairy Rock Crab

The hairy rock crab comprised 14.5 percent of all entrained cancer crab megalopae (Table 5-2). The annual estimate of entrainment for January – December 2000 was 1,965,950 (*S.E.* = 119,801) (Table 5-2). Estimates of period of entrainment risk used in the *ETM* analysis, and estimates of longevity and maturation used in the *FH* model were taken from demographic data reported for yellow crab *Cancer anthonyi* (Carroll and Winn 1982).

Empirical Transport Model (ETM)

The P_m estimate for hairy rock crab was 0.01 (*S.E.* = 0.634) based on a period of entrainment risk of 45 days (Anderson and Ford 1976, *in* Carroll and Winn 1982). The model included an adjustment for P_s because this taxon occupies nearshore habitats that extend well beyond the sampling areas. The largest fraction of the population was collected during the April survey (f_i = 0.4072) (Table 5-27). There were also several source water surveys where no hairy rock crab megalopae were collected even though entrainment of their larvae occurred during the period. *PE* estimates ranged from 0.0000 to 0.0723 (Table 5-27).

Table 5-27. *ETM* data for hairy rock crab *Cancer jordani*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0000	0.0000	0.0821	0.0156
28-Feb-00	0.0000	0.0000	0.0201	0.0076
27-Mar-00	0.0000	0.0000	0.0000	0.0000
24-Apr-00	0.0089	0.0020	0.4072	0.0299
15-May-00	0.0000	0.0000	0.0925	0.0113
12-Jun-00	0.0124	0.0137	0.1828	0.0309
10-Jul-00	0.0101	0.0109	0.0710	0.0115
08-Aug-00	0.0000	0.0000	0.0530	0.0155
05-Sep-00	0.0000	0.0000	0.0000	0.0000
02-Oct-00	0.0000	0.0000	0.0190	0.0067
13-Nov-00	0.0723	0.0849	0.0243	0.0053
18-Dec-00	0.0047	0.0049	0.0480	0.0077

Fecundity Hindcast Model (FH)

The total annual larval entrainment for hairy rock crab was used to estimate the number of breeding females needed to produce the number of megalopae entrained (Table 5-2). The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalopae was calculated assuming an age at maturation of 1.5 years and an average lifespan of 4.8 years (Table 5-28). The number of adult females hindcast from the megalopae entrained at the MBPP combined-cycle intake was 671 (90 percent C.I. = 240 to 1,877) (Table 5-28).

Table 5-28. Annual estimates of female hairy rock crab losses based on megalopal entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	671	419	1,877	240	1,637
Entrainment	1,965,950	119,801	738	603	135
Megalopal survival	0.0011	0.0003	1,099	409	690
# Eggs/year	1,530,907	459,272	1,099	409	690
Longevity	4.8	1.45	1,541	348	1,193
Maturation	1.5	0.45	941	571	370

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and survivorship (Table 5-28).

Adult Equivalent Loss (AEL)

No independent estimate of survival of hairy rock crab between age of entrainment and adult stage was found in the literature so *AEL* could not be calculated.

Summary

The P_m estimate indicates a low potential for effects on the hairy rock crab population. Similar to brown rock crab megalopae, the megalopal concentrations among the source water stations were highest at the Estero Bay station (Station 5) (Figure 3-32). They were lowest at the inner bay stations (stations 3 and 4). Although there is little known about the life history of hairy rock crabs, it is expected that their larvae can become widely distributed in nearshore waters. Their occurrence in Morro Bay intake samples is probably the result of onshore water movements as evidenced by their greater abundances at the Estero Bay station (Figure 3-52).

The results from the *FH* model indicated that the annual entrainment represented the loss of approximately 671 adult female hairy rock crabs. In the absence of any fishery data for this species it is impossible to provide any context for the losses predicted by the *ETM* or *FH* results.

5.1.3.13 Yellow Crab

The yellow crab comprised 8.2 percent of all entrained cancer crab megalopae (Table 5-2). The annual estimate of entrainment for January – December 2000 was 1,116,099 (*S.E.* = 51,687) (Table 5-2). Estimates of period of entrainment risk used in the *ETM* analysis, and estimates of longevity, maturation, fecundity, growth, and survival used in the *FH* model were derived from values reported from Anderson and Ford (1976) *in* Carroll and Winn (1982).

Empirical Transport Model (ETM)

The P_m estimate for yellow crab was 0.03 (*S.E.* = 1.34) based on a period of entrainment risk of 45 days. The model included an adjustment for P_s because this taxon occupies nearshore habitats that extend well beyond the sampling areas. The largest fraction of the population was collected during the December survey (f_i = 0.4427) (Table 5-29). Yellow crab megalopae were collected throughout the year although there were several source water surveys where no yellow crab megalopae were collected. *PE* estimates ranged from 0.0000 to 0.1000 (Table 5-29).

Table 5-29. *ETM* data for yellow crab *Cancer anthonyi*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0000	0.0000	0.0000	0.0000
28-Feb-00	0.0000	0.0000	0.0175	0.0066
27-Mar-00	0.0000	0.0000	0.0133	0.0050
24-Apr-00	0.0000	0.0000	0.0492	0.0105
15-May-00	0.0000	0.0000	0.0173	0.0065
12-Jun-00	0.0566	0.0435	0.1374	0.0229
10-Jul-00	0.0000	0.0000	0.1371	0.0173
08-Aug-00	0.0077	0.0081	0.0300	0.0086
05-Sep-00	0.0000	0.0000	0.0202	0.0067
02-Oct-00	0.1000	0.1173	0.0241	0.0076
13-Nov-00	0.0863	0.0392	0.1112	0.0137
18-Dec-00	0.0273	0.0295	0.4427	0.0250

Fecundity Hindcast Model (FH)

The total annual larval entrainment for yellow crab was used to estimate the number of breeding females needed to produce the number of megalopae entrained (Table 5-2). The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalopae was calculated assuming an age at maturation of 1.5 years and an average lifespan of

4.8 years (Table 5-30). The number of adult females hindcast from the megalopae entrained at the MBPP combined-cycle intake was 315 (90 percent C.I. = 113 to 880) (Table 5-30).

Table 5-30. Annual estimates of female yellow crab losses based on megalopal entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	315	197	880	113	767
Entrainment	1,116,099	51,687	339	291	48
Megalopal survival	0.0008	0.0002	516	192	324
# Eggs/year	2,600,000	780,000	516	192	324
Longevity	4.8	1.45	724	164	560
Maturation	1.5	0.45	442	268	174

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and survivorship (Table 5-30).

Adult Equivalent Loss (AEL)

No independent estimate of survival of yellow crab between age of entrainment and adult stage was found in the literature so *AEL* could not be calculated.

Summary

Yellow crab are a component of the local rock crab fishery. The P_m estimate indicates a low potential for effects on the yellow crab population. A comparison of larval concentrations among the source water stations showed that they were highest at Estero Bay Station 5 (Figure 3-55). They were lowest at the inner bay stations (stations 3 and 4). Similar to brown rock crab, yellow crab megalopae likely become widely distributed in nearshore waters. Their occurrence in Morro Bay intake samples is probably the result of onshore water movements as evidenced by their greater abundances at the station in Estero Bay (Figure 3-55). The results from the *FH* model indicated that the annual entrainment represented the loss of approximately 315 adult female yellow crabs. The *ETM* results and small estimate from the *FH* model indicate little potential for impacts to this species.

5.1.3.14 Slender Crab

The slender crab comprised 3.5 percent of all entrained cancer crab megalopae (Table 5-2). The annual estimate of entrainment for January – December 2000 was 470,025 (*S.E.* = 35,475)

(Table 5-2). This species of cancer crab is not taken as part of the local commercial and recreational rock crab fishery. Early life history of slender crab was described by Ally (1975), and some demographic data were also reported in Orensanz and Gallucci (1988).

Empirical Transport Model (ETM)

The P_m estimate for slender crab was 0.01 (*S.E.* = 0.60) based on a period of entrainment risk of 41.6 days, half of the average megalopal stage duration including the cumulative average zoeal stage durations (Ally 1975). The model included an adjustment for P_s because this taxon occupies nearshore habitats that extend well beyond the sampling areas. The largest fraction of the population was collected during the February survey (f_i = 0.3861) (Table 5-31). Slender crab megalopae were collected throughout the year although there were several source water surveys where no slender crab megalopae were collected. *PE* estimates ranged from 0.0000 to 0.4129 (Table 5-31).

Table 5-31. *ETM* data for slender crab *Cancer gracilis*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0000	0.0000	0.2132	0.0366
28-Feb-00	0.0000	0.0000	0.3861	0.0358
27-Mar-00	0.0428	0.0447	0.0601	0.0178
24-Apr-00	0.0000	0.0000	0.0196	0.0112
15-May-00	0.0000	0.0000	0.0000	0.0000
12-Jun-00	0.4129	0.5839	0.0145	0.0072
10-Jul-00	0.0000	0.0000	0.0109	0.0063
08-Aug-00	0.0000	0.0000	0.0000	0.0000
05-Sep-00	0.0000	0.0000	0.0757	0.0196
02-Oct-00	0.0000	0.0000	0.0449	0.0155
13-Nov-00	0.0000	0.0000	0.1229	0.0246
18-Dec-00	0.0098	0.0099	0.0522	0.0154

Fecundity Hindcast Model (FH)

The total annual larval entrainment for slender crab was used to estimate the number of breeding females needed to produce the number of megalopae entrained (Table 5-2). The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalopae was calculated assuming an age at maturation of 1.0 year and an average lifespan of 3.0 years (Table 5-32). The number of adult females hindcast from the megalopae entrained at the MBPP combined-cycle intake was 605 (90 percent C.I. = 211 to 1,737) (Table 5-32).

Table 5-32. Annual estimates of female slender crab losses based on megalopal entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	605	388	1,737	211	1,526
Entrainment	470,025	35,475	680	530	150
Megalopal survival	0.0014	0.0004	991	369	622
# Eggs/year	555,583	166,675	991	369	622
Longevity	3.0	0.90	1,456	309	1,147
Maturation	1.0	0.30	889	507	382

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and survivorship (Table 5-32).

Adult Equivalent Loss (AEL)

No independent estimate of survival of slender crab between age of entrainment and adult stage was found in the literature so *AEL* could not be calculated.

Summary

Slender crab are not commercially harvested. The P_m estimate indicates a low potential for effects on the slender crab population. The results from the *FH* model indicate that the annual entrainment represented the loss of approximately 605 adult female slender crabs.

5.1.3.15 Red rock Crab

The red rock crab comprised 0.4 percent of all entrained cancer crab megalopae (Table 5-2). The annual estimate of entrainment for January – December 2000 was 85,705 (*S.E.* = 14,570) (Table 5-2). This species of cancer crab is taken as part of the local commercial and recreational rock crab fishery. Estimates of the period of entrainment risk used in the *ETM* analysis, and estimates of longevity, maturation, fecundity, growth, and survival used in the *FH* model were based on values reported in Carroll and Winn (1989) and Starr et al. (1998).

Empirical Transport Model (ETM)

The P_m estimate for red rock crab was 0.02 (*S.E.* = 2.10) based on a period of entrainment risk of 97 days (Trask 1970, *in* Carroll and Winn 1989). The model included an adjustment for P_s because this taxon occupies nearshore habitats that extend well beyond the sampling areas. *PE* estimates ranged from 0.0000 to 0.0724 (Table 5-33). The largest fraction of the population was collected during the September survey (f_i = 0.3247) (Table 5-33). Red rock crab larvae were collected only from summer through late fall. Although they were not present in winter surveys in 2000 their high abundance in the December 2000 survey indicates that their abundance may persist into winter in some years (Table 5-33).

Table 5-33. *ETM* data for red rock crab *Cancer productus*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0000	0.0000	0.0000	0.0000
28-Feb-00	0.0000	0.0000	0.0000	0.0000
27-Mar-00	0.0000	0.0000	0.0000	0.0000
24-Apr-00	0.0000	0.0000	0.0000	0.0000
15-May-00	0.0000	0.0000	0.0000	0.0000
12-Jun-00	0.0000	0.0000	0.0000	0.0000
10-Jul-00	0.0000	0.0000	0.2136	0.0711
08-Aug-00	0.0000	0.0000	0.0000	0.0000
05-Sep-00	0.0354	0.0386	0.3247	0.0783
02-Oct-00	0.0000	0.0000	0.0569	0.0391
13-Nov-00	0.0724	0.0858	0.1329	0.0612
18-Dec-00	0.0000	0.0000	0.2720	0.0747

Fecundity Hindcast Model (FH)

The total annual larval entrainment for red rock crab was used to estimate the number of breeding females needed to produce the number of megalopae entrained (Table 5-2). The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalopae was calculated assuming an age at maturation of 1.5 years and an average lifespan of 4.8 years (Table 5-34). The number of adult females hindcast from the megalopae entrained at the MBPP combined-cycle intake was 21 (90 percent C.I. = 7 to 60) (Table 5-34).

Table 5-34. Annual estimates of female red rock crab losses based on megalopal entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	21	13	60	7	53
Entrainment	85,705	14,570	27	15	12
Megalopal survival	0.0017	0.0005	34	13	21
# Eggs/year	1,492,500	447,750	34	13	21
Longevity	4.8	1.45	48	11	37
Maturation	1.5	0.45	29	18	11

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and survivorship (Table 5-34).

Adult Equivalent Loss (AEL)

No independent estimate of survival of red rock crab between age of entrainment and adult stage was found in the literature so *AEL* could not be calculated.

Summary

Red rock crab are a component of the local rock crab fishery. The P_m estimate (2 percent) indicates a low potential for effects on the red rock crab population. The *ETM* results and small estimate from the *FH* model indicate little potential for impacts to this species.

5.1.3.16 Dungeness Crab

Dungeness crab comprised 0.6 percent of all entrained cancer crab megalopae (Table 5-2). The annual estimate of entrainment for January – December 2000 was 54,650 (*S.E.* = 12,002) (Table 5-2). This species of cancer crab is taken locally in the commercial and recreational fisheries. Estimates of the period of entrainment risk used in the *ETM* analysis, and estimates of longevity, maturation, fecundity, growth, and survival used in the *FH* model were based on values reported in the literature (Reilly 1983, Carroll and Winn 1989, Starr et al. 1998).

Empirical Transport Model (ETM)

The *ETM* estimate for Dungeness crab was 0.05 (*S.E.* = 5.34) based on a period of entrainment risk of 108 days (Reilly 1983). The model included an adjustment for P_s because this taxon occupies nearshore habitats that extend well beyond the sampling areas. Dungeness crab megalopae were collected over a fairly short period of time based on their long period of entrainment risk. They were collected during only one source water survey in May, and were present in entrainment samples only during May and June (Table 5-35). *PE* estimates ranged from 0.0000 to 0.1506 (Table 5-35).

Table 5-35. *ETM* data for Dungeness crab *Cancer magister*. *ETM* calculations based on Morro Bay volume = 15,686,663 m^3, Estero Bay study area volume = 20,915,551 m^3, and daily cooling water volume = 1,619,190 m^3. An adjustment for P_s was used with these data in calculating P_m because this taxon occupies both bay and nearshore habitats that extend beyond the areas sampled.

Survey Date	*PE* Estimate	*PE* Std. Error	f_i	f_i Std. Error
17-Jan-00	0.0000	0.0000	0.0000	0.0000
28-Feb-00	0.0000	0.0000	0.0000	0.0000
27-Mar-00	0.0000	0.0000	0.0000	0.0000
24-Apr-00	0.0000	0.0000	0.0000	0.0000
15-May-00	0.1506	0.1353	0.3821	0.1069
12-Jun-00	0.0000	0.0000	0.6179	0.1069
10-Jul-00	0.0000	0.0000	0.0000	0.0000
08-Aug-00	0.0000	0.0000	0.0000	0.0000
05-Sep-00	0.0000	0.0000	0.0000	0.0000
02-Oct-00	0.0000	0.0000	0.0000	0.0000
13-Nov-00	0.0000	0.0000	0.0000	0.0000
18-Dec-00	0.0000	0.0000	0.0000	0.0000

Fecundity Hindcast Model (FH)

The total annual larval entrainment for Dungeness crab was used to estimate the number of breeding females needed to produce the number of megalopae entrained (Table 5-2).
The estimated number of breeding females (*FH*) whose fecundity equals the estimated total loss of entrained megalopae was calculated assuming an age at maturation of 2.0 years and an average lifespan of 6.0 years (Table 5-36). The number of adult females hindcast from the megalopae entrained at the MBPP combined-cycle intake was 27 (90 percent C.I. = 9 to 82) (Table 5-36).

Table 5-36. Annual estimates of female Dungeness crab losses based on megalopal entrainment estimates using Fecundity Hindcast model for January – December 2000. Upper and lower estimates represent the changes in the model estimates that result from varying the value of the corresponding parameter in the model.

Parameter	Parameter Estimate	Parameter Std. Error	Upper Estimate of *FH*	Lower Estimate of *FH*	*FH* Range
Fecundity Hindcast	27	18	82	9	73
Entrainment	54,650	12,002	37	17	20
Megalopal survival	0.0008	0.0002	45	17	28
# Eggs/year	1,250,000	375,000	45	17	28
Longevity	6.0	1.80	66	14	52
Maturation	2.0	0.60	40	23	17

The uncertainty of our *FH* estimate was attributed by sensitivity analysis to the model parameters of average lifespan, fecundity, and survivorship (Table 5-36).

Adult Equivalent Loss (AEL)

No independent estimate of survival of Dungeness crab between age of entrainment and adult stage was found in the literature so *AEL* could not be calculated.

Summary

Dungeness crab are taken in the Morro Bay area in both recreational and commercial fisheries. The P_m estimate (5 percent) indicates a low potential for effects on the Dungeness crab population. This is also reflected in the *FH* estimate of losses of only 27 adult female Dungeness crabs.

5.1.4 Summary of Entrainment Effects

The concentrations of larval fishes and megalopal cancer crabs collected at the MBPP intake station were used to estimate entrainment losses of the MBPP new combined-cycle units by extrapolating to both a representative number 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 cancer crabs in Table 5-37(a) and (b), respectively.

Table 5-37. Summary of estimated MBPP combined-cycle entrainment for abundant fishes and cancer crabs based on *ETM*, *FH*, and *AEL* models using entrainment and source water larval concentrations and Estero Bay study area and Morro Bay volumes (January – December 2000).

(a) Fishes

	Total Entrainment	*2*FH*	*AEL*	P_m (a)	P_m (b)
unidentified gobies	3.9×10^8	796,298	267,850	0.1153	0.4285
Pacific staghorn sculpin§	1.7×10^7	*	*	0.0513	
northern lampfish§	1.5×10^7	*	*	0.0238	
shadow goby	1.3×10^7	12,678	7,436	0.0279	0.0622
combtooth blennies	1.0×10^7	8,722	8,084	0.4913	0.7242
KGB rockfishes§	6.4×10^6	26	23	0.0240	
jacksmelt	6.3×10^6	*	*	0.2194	0.4419
white croaker§	3.0×10^6	106	*	0.0215	
Pacific herring	3.0×10^6	86	532	0.0118	0.0176
cabezon§	2.9×10^6	*	*	0.0371	

§ - taxa that used an *ETM* model adjusted by P_s. Average P_m = 0.10.

	FH	Total Entrainment	Egg Survival	Yolk-sac Survival	Larvae Survival	Average Lifespan (years)	Age at Maturation (years)	Eggs/year
unidentified gobies	398,149	3.9×10^8	*	*	0.7525	2.0	0.5	1,750
Pacific staghorn sculpin	*	1.7×10^7	*	*	*	*	*	*
northern lampfish	*	1.5×10^7	*	*	*	*	*	*
shadow goby	6,339	1.3×10^7	*	*	0.7101	4.5	1.5	2,000
combtooth blennies	4,361	1.0×10^7	*	*	0.7805	7	2	1,180
KGB rockfishes	13	6.4×10^6	*	*	0.4601	15	5	213,000
jacksmelt	*	6.3×10^6	*	*	*	*	*	*
white croaker	53	3.0×10^6	*	*	0.1775	12	2	105,000
Pacific herring	43	3.0×10^6	0.40	*	0.6174	11	2.5	67,000
cabezon	*	2.9×10^6	*	*	*	*	*	*

	AEL	Total Entrainment	Early Larval Survival	Late Larval Survival	Early Juvenile Survival	Late Juvenile Survival	Pre-Recruit Survival
unidentified gobies	267,850	3.9×10^8	0.0239	0.0899	*	*	0.3162
Pacific staghorn sculpin	*	1.7×10^7	*	*	*	*	*
northern lampfish	*	1.5×10^7	*	*	*	*	*
shadow goby	7,436	1.3×10^7	0.0113	*	*	*	0.0489
combtooth blennies	8,084	1.0×10^7	0.0128	*	*	*	0.0628
KGB rockfishes	23	6.4×10^6	0.1313	0.0408	0.0082	0.1259	0.6453
jacksmelt	*	6.3×10^6	*	*	*	*	*
white croaker	*	3.0×10^6	*	*	*	*	*
Pacific herring	532	3.0×10^6	0.01620	*	*	*	0.0108
cabezon	*	2.9×10^6	*	*	*	*	*

*Unavailable information or value that could not be computed.

(a) P_m values calculated using average period of entrainment risk.

(b) *ETM* values calculated using maximum period of entrainment risk. Estimates for taxa calculated using *ETM* values with P_s adjustments are identical to values calculated using average period of entrainment risk.

Table 5-37 (continued). Summary of estimated MBPP combined-cycle entrainment for abundant fishes and cancer crabs based on *ETM*, *FH*, and *AEL* models using entrainment and source water larval concentrations and Estero Bay study area and Morro Bay volumes (January – December 2000).

(b) Cancer Crabs

	Total Entrainment	2*FH	P_m
brown rock crab§	$9.7x10^6$	5,192	0.0275
hairy rock crab§	$2.0x10^6$	1,342	0.0084
yellow crab§	$1.1x10^6$	630	0.0310
slender crab§	$4.7x10^5$	1,210	0.0079
red rock crab§	$8.6x10^4$	42	0.0204
Dungeness crab§	$5.5x10^4$	54	0.0531

§ - *ETM* model adjusted by P_s. Average P_m = 0.02.

	Total Entrainment	FH	Egg Survival	Megalopal Survival	Eggs/year	Average Lifespan (years)	Age at Maturation (years)
brown rock crab	$9.7x10^6$	2,596	1.0	0.001069	1,756,450	5.5	1.5
hairy rock crab	$2.0x10^6$	671	1.0	0.001149	1,530,907	4.8	1.5
yellow crab	$1.1x10^6$	315	1.0	0.000817	2,600,000	4.8	1.5
slender crab	$4.7x10^5$	605	1.0	0.001398	555,583	3.0	1.0
red rock crab	$8.6x10^4$	21	1.0	0.001658	1,492,500	4.8	1.5
Dungeness crab	$5.5x10^4$	27	1.0	0.000802	1,250,000	6.0	2.0

(a) *ETM* values calculated using average period of entrainment risk.

The *PE* values for each source water survey used in the *ETM* are estimates of the daily incremental mortality due to entrainment for each survey. The P_m estimates are based on representative estimates of Morro Bay's source water and entrainment populations. Several of the taxa discussed in the previous sections have local populations that extend into nearshore and offshore waters beyond the area sampled during the source water studies. The *ETM* model for these taxa contained an additional term (P_s) to estimate the fraction of the local larval population sampled by the source water studies. The P_m estimates for these taxa indicated little risk due to entrainment because the source water population sampled represented only a proportion of the larger stock. The adult distributions in the local area of taxa groups like combtooth blennies, gobies, and topsmelt were better represented by the area sampled in the source water studies. The P_m estimates for these taxa indicated a larger potential for impacts due to entrainment. Combtooth blennies had the highest P_m estimates of incremental mortality due to entrainment indicating a potential for local population level impacts.

Results showed that larval concentrations vary considerably among source water stations. In many cases larvae for a taxon were collected from one station during a survey and were not collected at the same location the following survey. Many orders of magnitude differences in concentration also occurred among the stations. Most of these differences coincided with differences in habitat among the stations. The combtooth blennies primary habitat is the pier pilings and fouling communities found in the area of Morro Bay between the Embarcadero and the power plant intakes. During source water surveys the concentrations of combtooth blenny larvae were almost always highest at the stations (2 and 3) located in this area of the bay. The high concentrations at these two stations, one being the intake station, have resulted in the large P_m estimates for this taxa group. Other areas in the bay with similar habitat were not sampled, potentially underestimating the source water population for this taxa group. The large P_m estimates for these taxa should be interpreted as a strong indicator of entrainment impacts, however, it should not be interpreted that 49 percent of the larval population is lost annually due to entrainment. A population would be unlikely to sustain continued annual losses of larval production of this magnitude without some decline. The continued presence of high numbers of combtooth blenny larvae indicates that this has not occurred.

The *AEL* and *FH* modeling results used generalized larval mortality information that may not accurately represent the specific species' larval survival rates. In the case of combtooth blennies and unidentified gobies, there is uncertainty about the actual species composition of the groups, and consequently the specific life history characteristics used in the models may not be representative of the group. The models include the assumption that the parameters are representative for the time period of collection and this may not hold for these groups whose composition may change through the year due to variations in the reproductive cycles among the species within the group.

Information on the size of the species' adult fish populations is required to convert the *FH* or *AEL* estimates into fractional losses that can be compared to fishery data. However, the majority of taxa found in our study are not commercially or recreationally harvested. There was no context for these estimates because of the absence of a population assessment or fishery data. For example, egg and larval mortality data for unidentified gobies allowed the application of multiple approaches, but because this taxon is not harvested or monitored at the population level, the losses cannot be compared to any standing stock of gobies.

For those species with both *FH* and *AEL* estimated losses, the model results can be compared directly using the relationship $2FH \equiv AEL$. This conversion requires that ages of *FH* and *AEL* individuals are equal in a 50:50 sex ratio. Results for abundant taxa that were in close agreement with the relationship $2FH \equiv AEL$ provide 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. Our results for combtooth blennies and KGB rockfishes fit this relationship.

The length ranges from entrainment for most of the abundant larval fish taxa from these studies indicated 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 low concentrations of these later developmental stages in entrainment samples may indicate the presence of larval behavior (e.g., settlement to benthic habitats or migration into deeper areas away from the intakes) that separates them from risk to entrainment as they develop.

Many of the larval fishes entrained are small fishes as adults and as such are not commercially or recreationally harvested. There is also only limited information on the larval and adult life histories for these fishes and therefore we were only able to compute *FH* and *AEL* estimates for a limited number of these fishes (Table 5-37a). As might be expected due to the shallow water shoreline intake location, several of these taxa were entrained in relatively high numbers. The large *FH* and *AEL* estimates for these fishes corresponded to their high entrainment abundances.

The impacts of entrainment on source water populations can be evaluated by estimating the fractional losses to the population attributable to the CWIS. Estimates of source water populations were acquired from the California Department of Fish and Game (CDFG) or Pacific States Marine Fisheries Commission (PSMFC) commercial and sport catch data. Estimated entrainment losses were extrapolated to fishery losses using *FH* and *AEL* estimates. Life history data for computing *FH* and *AEL* were available for only a few taxa, and even fewer of those taxa had commercial fishery statistics for the Morro Bay area (Table 5-38). The total dollar value estimate of $192 – $246 underestimates the actual value due to the absence of adult estimates for important commercial taxa, such as cabezon. For cancer crabs, estimated fishery losses due to entrainment were made using *FH* estimates (Table 5-37b). An average weight of 0.34 and 0.45 kg for females and males, respectively, is reported for the Morro Bay area catch (Deborah Johnston, CDFG, pers. comm. 1999). The estimated dollar loss for cancer crabs from entrainment is $9,301 (Table 5-38).

In summary, the MBPP intake entrains large numbers of small (e.g., adult arrow goby are from 25.4 to 76.2 mm [1 – 3 in.]), nearshore fishes that are resident or commonly inhabit Morro Bay. The size of the P_m estimates for some of the fishes indicates that entrainment losses could impact their populations. Taxa such as Pacific staghorn sculpin, northern lampfish, KGB rockfishes, jacksmelt, white croaker, Pacific herring, cabezon, and cancer crabs have coastal adult populations well beyond the influence of the MBPP intakes. These taxa are less affected, as the source water surveyed is a small proportion of their potential local larval population. The entrainment mortalities for many of these taxa are a minute fractional loss based on the *FH* and *AEL* estimates of potential adult losses.

Table 5-38. Approximate value ($) of estimated losses due to entrainment at the MBPP for cancer crabs and selected groups of fishes (January – December 2000). Data from the California Department of Fish and Game unless otherwise noted.

	Total Entrainment	***2*FH***	***AEL***	**Source for Fishery Data[a]**	**1999 Landings at Morro Bay Ports (MT)**	**1999 Ex-vessel Value ($) at Morro Bay Ports**	**Approximate cost per kg ($)**	**Approximate weight per fish (kg)**	**Approximate Value ($) of Losses due to Entrainment - *2FH***	**Approximate Value ($) of Losses due to Entrainment - *AEL***
Fishes										
unidentified gobies	3.9×10^8	796,298	267,850	n.a.	n.a.	n.a.	*	*	*	*
Pacific staghorn sculpin	1.7×10^7	*	*	n.a.	n.a.	n.a.	*	*	*	*
northern lampfish	1.5×10^7	*	*	n.a.	n.a.	n.a.	*	*	*	*
shadow goby	1.3×10^7	12,678	7,436	n.a.	n.a.	n.a.	*	*	*	*
combtooth blennies	1.0×10^7	8,722	8,084	n.a.	n.a.	n.a.	*	*	*	*
KGB rockfishes	6.4×10^6	26	23	PacFin	74.4	$611,600	$8.22	1.00	$214	$189
jacksmelt	6.3×10^6	*	*	CDFG	n.a.	n.a.	$1.46[b]	*	*	*
white croaker	3.0×10^6	106	*	CDFG	n.a.	n.a.	$1.36[b]	0.2125	$31	*
Pacific herring	3.0×10^6	86	532	CDFG	n.a.	n.a.	$0.09[b]	0.0690	$1	$3
cabezon	2.9×10^6	*	*	CDFG	58.7	516,529	$8.80	*	*	*
Total Fishes									**$246**	**$192**
Cancer crabs									–	*
brown rock crab	9.7×10^6	5,192	*		–	–	–		–	–
hairy rock crab	2.0×10^6	1,342	*		–	–	–		–	–
yellow crab	1.1×10^6	630	*		–	–	–		–	–
slender crab	4.7×10^5	1,210	*		–	–	–		–	–
red rock crab	8.6×10^4	42	*		–	–	–		–	–
Dungeness crab	5.5×10^4	54	*		–	–	–		–	–
Total Crabs	**1.3×10^7**	**8,470**	*	CDFG	**42.2**	**$117,247**	**$2.78**		**$9,301**	*

n.a. – no information available

* - value could not be calculated

[a] – Sources for fishery data: PacFin – Reports #010W and #020W from Pacific States Marine Fisheries Commission (PSMFC) website database (www.psmfc.org/pacfin/data) for 1999 Port Group Groundfish Catch; and CDFG – California Department of Fish and Game. 2000. Final California Commercial Landings for 1999. PacFin and CDFG data are attached in Appendix I.

MT (metric ton) = 1,000 kg (2,205 lb)

5.2 Summary of Impingement Effects

The impacts of impingement on source water populations were also evaluated by estimating the fractional losses to the population attributable to the CWIS. Impingement rates and biomass estimates from this study provided estimates of impingement losses that were compared with source water abundance and biomass estimates to estimate potential impingement effects on local populations. Estimates of source water populations were collected from the same sources (CDFG and PSMFC) used for interpreting entrainment results (Appendix I).

Approximately 11,000 (167 kg [369 lb]) fishes and 7,600 (52 kg [115 lb]) crabs, shrimps, cephalopods, and sea urchins were collected in weekly impingement surveys from September 9, 1999 and through September 8, 2000. Five fish taxa comprised 90 percent by number of fish impingement (Units 1-4 combined), while seven taxa made up 91 percent of impingement by weight. Three fish species were impinged in both high numbers and biomass at the MBPP: northern anchovy (ranked 1st by both number and biomass), topsmelt (ranked 2nd by number and 3rd by biomass), and plainfin midshipman (ranked 3rd by number and 4th by biomass). Among these, only northern anchovy are targeted commercially in a small bait fishery in Morro Bay and topsmelt are occasionally taken by recreational fishers (CDFG unpubl. data,). The other two fishes comprising the top 90 percent by abundance were speckled sanddab and Pacific staghorn sculpin. The data for fishes were expanded by flow volumes to estimate impingement totals of approximately 74,000 fishes with a combined weight of 1.1 metric tons (MT) (2,500 lb) or 1.34 short tons (T) for the year-long study period.

Twelve taxa comprised 90 percent by number of the macroinvertebrates impinged at the MBPP (Units 1-4 combined) while nine taxa made up greater than 90 percent by weight. Market squid *Loligo opalescens* were collected in highest abundance, accounting for 34 percent by number and 11 percent by weight of the impingement totals. Xantus' swimming crabs *Portunus xantusii* had the highest biomass of any invertebrates collected, accounting for 26 percent of the total biomass and 9 percent of the total abundance. Five other species were in the top 90 percent by number and weight: *Crangon nigricauda*, *Cancer jordani*, *C. antennarius*, *Pugettia producta*, and *Penaeus californiensis*. The impingement data for macroinvertebrates were expanded by flow volumes to estimate impingement totals for the year of approximately 53,000 individuals weighing 360 kg (790 lb).

The impingement rates measured at the existing CWIS will be decreased with the CWIS planned for the new facility due to reduced intake volumes and intake approach velocities . However, it is not possible to estimate the level of reduction because there is not a predictable relationship between impingement and intake volume. However, data requests[1,2] through the CEC processes required Duke Energy to make this projection. Estimates in this report of impingement for the study period were computed using flow rates for the existing units (184,000 gpm for Units 1 and 2, and 280,000 gpm for Units 3 and 4). Impingement is dependent upon numerous factors including tidal height and current, season, debris volume, and plant operations. Therefore, it is not realistic to recalculate impingement by substituting the CWIS flow volumes for the proposed units for the flow rates measured during sampling. In addition, estimates recalculated using the reduced flow volumes would merely reflect the proportional reduction in volume between the existing and proposed units. Responses to these data requests assumed a linear relationship between intake volume and impingement rates; data analyzed by this method demonstrated, as expected, a reduction in impingement with the new CWIS proportional to the reduced volume.

One way to put these losses into context is to compare the biomass losses to a worst-case scenario using existing fishery statistics for one of the most valuable ($/lb) California fishes, cabezon. Cabezon landings in 1999 at the Morro Bay area ports totaled 58.7 MT, and were valued at $516,529 (Table 5-38). If all of the impinged fishes at the MBPP had been cabezon (actually only 2 percent by weight of impingement collections), then the 1.1 MT estimated impingement losses at the MBPP would be valued at around $9,680 per year. This estimate assumes all of the fish would have been caught and sold.

The PSMFC database reports on statewide fish landings places many fishes into broad groups (e.g., flatfishes excluding California halibut, all rockfishes, and roundfishes like northern anchovy and Pacific sardine) while others are reported as individual taxa (e.g., cabezon, lingcod, kelp greenling, and leopard shark) (Table 5-39). Using these taxonomic groupings for fishes impinged at the MBPP and using only the groups that have reported landings from the PSMFC or CDFG (2000), the estimated value of $805 is much smaller than the value estimated using only cabezon (Table 5-39). The total includes estimated values for fishes not landed at Morro Bay. The value per kg for these fishes was calculated from CDFG statewide landings data (CDFG 2000). There are also taxa from impingement that are caught as part of the local recreational fishery that are not recorded by the PSMFC or CDFG.

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[1] Morro Bay Power Plant Project. Responses to CAPE March 9, 2001 Data Requests. Data Request Letter #156. Using actual numbers of fish and invertebrates collected in 44 samples and applying the intake volume during the temporal stratums in which they were impinged to compute number per volume per unit time, please calculate total annual impingement based on maximum CWIS flow for the existing and for the proposed units and provide these calculations.

[2] Morro Bay Power Plant Project. Responses to CAPE March 9, 2001 Data Requests. Data Request Letter #161. Using actual numbers of fish and invertebrates collected in 44 samples and applying the intake volume during the temporal stratums in which they were impinged to compute number per volume per unit time, please calculate total annual impingement based on maximum CWIS flow for the existing and for the proposed units and provide these calculations.

The total projected dollar value of $456 associated with the MBPP impingement losses for invertebrate species is also low (Table 5-40). The values per kg for the invertebrate taxa were obtained from the 1999 CDFG commercial landings data for the port area of Morro Bay (CDFG 2000). The estimate also includes values for invertebrate groups not landed at Morro Bay. The value per kg for these invertebrates, that included groups like bay shrimp and octopus, was calculated from CDFG statewide landings data (CDFG 2000).

Table 5-39. Approximate dollar value of estimated impingement losses for selected taxonomic groups of fishes at MBPP for the study period. Values for each species were based on landings data from the Pacific States Marine Fisheries Commission's (PSMFC) Pacific Fisheries Information Network (PacFin) internet database and California Department of Fish and Game (2000), Final California Commercial Landings for 1999.

	Estimated # Impinged for Study Period	Estimated Weight (kg) Impinged for Study Period	1999 Landings at Morro Bay Ports (MT)	1999 Ex-vessel Value at Morro Bay Ports ($)	Approximate Cost ($) per kg	Approximate Value ($) of Estimated Impingement Losses
Northern anchovy	54,170	434.3 (957.5 lb)	2.0[b] (4,459 lb)	$892	$0.44	$191.10
Atherinidae (silversides)	4,170	137.5 (303.1 lb)			$0.55 [b, c]	$75.63
Plainfin midshipman	3,944	152.6 (336.4 lb)			$0.12 [b, c]	$18.31
Flatfishes	3,777	12.3 (27.2 lb)	505.8[a] (1,115,098 lb)	$411,400	$0.81	$9.96
Paralichthidae	2,655	8.9 (19.6 lb)				
Pleuronectidae	1,122	3.4 (7.5 lb)				
Pacific staghorn sculpin	1,511	16.9 (37.3 lb)			$7.35 [b, c]	$124.21
Surfperches	897	26.4 (58.2 lb)	0.8[b] (1,712 lb)	$3,062	$3.83	$101.11
Rockfishes	448	9.5 (20.9 lb)	401.9[a] (886,038 lb)	$1,121,000	$2.79	$26.51
Pacific sardine	421	24.4 (53.73 lb)			$0.08 [b, c]	$1.95
Cabezon	349	23.7 (52.24 lb)	58.7[b] (129,423 lb)	$516,529	$8.80	$208.56
Lingcod	224	1.47 (3.24 lb)	13.1[a] (28,881 lb)	$38,500	$2.94	$4.32
Bat ray	173	47.0 (103.6 lb)			$0.59 [b, c]	$27.73
Kelp greenling	38	1.4 (3.1 lb)	1.8[a] (3,968 lb)	$19,800	$11.00	$15.40
White croaker	22	0.04 (0.08 lb)			$1.36 [b, c]	$0.05
Leopard shark	7	0.2 (0.44 lb)	0.1[a] (221 lb)	$100	$1.00	$0.20
Pacific mackerel	6	0	0.03[b] (69 lb)	$28	$0.90	$0.00
Total Dollar Value						**$805.04**

[a] – Source for fishery data: PacFin – Reports #010W and #020W from Pacific States Marine Fisheries Commission (PSMFC) website database (www.psmfc.org/pacfin/data) for 1999 Port Group Groundfish Catch

[b] – Source for fishery data: California Department of Fish and Game. 2000. Final California Commercial Landings for 1999.

[c] – Values calculated from statewide landings for 1999 reported in CDFG (2000), because no data were available for the port of Morro Bay.

Table 5-40. Approximate dollar value of estimated impingement losses for selected taxonomic groups of invertebrates at MBPP for the study period. Values for each species are based on landings data from California Department of Fish and Game (2000), Final California Commercial Landings for 1999.

	Estimated # Impinged for Study Period	Estimated Weight (kg) Impinged for Study Period	1999 Landings at Morro Bay Ports (MT)	1999 Ex-vessel Value at Morro Bay Ports ($)	Approximate Cost ($) per kg	Approximate Value ($) of Estimated Impingement Losses
Cancer Crabs	4,986	101.0 (222.7 lb)	42.2 (93,055 lb)	$117,247	$2.78	$280.78
Cancer antennarius brown rock crab	3,894	82.3 (181.3 lb)				
Cancer anthonyi yellow crab	264	1.9 (4.3 lb)				
Cancer productus red rock crab	580	13.7 (30.3 lb)				
Cancer magister Dungeness crab	248	3.0 (6.7 lb)				
Shrimp and Prawns						
Crangon spp. bay shrimp	8,971	17.2 (37.9 lb)			$7.59[a]	$130.55
Pandalus platyceros spot prawn	16	0.6 (1.2 lb)	57.1 (126,000 lb)	$882,126	$15.45	$9.27
Cephalopods						
Loligo opalescens Market squid	16,814	38.0 (83.8 lb)	17.9 (39,512 lb)	$5,330	$0.30	$11.40
Octopus spp.	293	16.4 (36.1 lb)			$1.49[a]	$24.44
Total Dollar Value						**$456.44**

[a] – Values calculated from statewide landings for 1999 reported in CDFG (2000), because data were limited or not available for the port area of Morro Bay.

5.2.1 Comparison of Annual Biomass of Impinged Fishes at Various California Coastal Power Plants

The annual biomass of impinged fishes from four power plants was compiled to provide a comparison among California coastal power plants. The annual biomass (gr/million m^3 of cooling water) of impinged fishes at MBPP, San Onofre Nuclear Power Station (SONGS), Moss Landing Power Plant (MLPP), and Diablo Canyon Power Plant (DCPP) is presented in Table 5-41. The data in the table were collected during the following periods:

- MBPP data collected from September 1999 – September 2000 (Section 4.0, this document),
- MBPP data collected from January 1978 – December 1978 (PG&E 1982),
- SONGS annual averages for the period 1984 – 1995 (SCE Annual Reports, 1985 – 1996; Appendix B),
- MLPP annual values for the period of March 1979 – March 1980 (PG&E 1983), and
- DCPP data collected from April 1985 – March 1986 (PG&E 1988).

Power plant CWIS location and design are two of the many factors that influence impingement. The comparison below shows that the annual impinged biomass at the Diablo Canyon Power Plant was lowest among the four power plants. DCPP's CWIS is located in an artificially created cove that is sheltered from the open coast. MLPP is located in a harbor at the entrance to a tidal lagoon (Elkhorn Slough), the harbor is protected by breakwaters from the open coast of Monterey Bay. The MBPP CWIS is located in an estuary that has similar habitats to those found near the MLPP. Moss Landing and Morro Bay power plants had similar biomass rates during the studies conducted in the late 1970s. The high biomass rate of SONGS is also a function of the location and design of the intake. SONGS Units 2 and 3 intake is an offshore vertical riser in the open ocean; large numbers of fishes and invertebrates and occasionally even marine mammals are entrapped by the high approach velocities and impinged at the shoreline traveling screens.

Table 5-41. Annual biomass (g/million m^3 flow) of impinged fishes at Morro Bay Power Plant, San Onofre Nuclear Generating Station (SONGS), Moss Landing Power Plant, and Diablo Canyon Power Plant. SONGS data also include fishes collected during treat treatments.

Family and Scientific Name	Common Name	Morro Bay 1999-2000 Units 1-4	Morro Bay 1978-1979 Units 3-4*	Moss Landing 1979-1980 Units 1–7	San Onofre 1984-1995** Units 2-3	Diablo Canyon 1985-1986 Units 1-2
Clupeidae	sardines & herring	32.28	0.58	353.53	827.08	-
Engraulididae	anchovies	572.55	467.83	1,753.23	1,376.46	-
Batrachoididae	midshipman	201.12	1,622.84	238.78	93.79	12.45
Atherinidae	jacksmelt & grunion	181.32	1,123.15	323.24	2,809.88	0.7
Scorpaenidae	rockfishes	12.50	187.62	197.71	6.15	17.67
Cottidae	sculpins	57.16	48.24	345.04	70.97	1.24
Pristipomatidae	salema & sargo	-	-	-	539.45	-
Scaenidae	croakers & white sea bass	0.05	19.79	63.90	7,348.24	0.51
Kyphosidae	zebraperch	-	-	0.00	155.53	0
Embiotocidae	surfperch	34.82	683.63	801.84	211.92	6.54
Serranidae	kelp bass and sand bass	-	0.18	-	146.38	-
Clinidae	kelpfishes & fringeheads	.99	6.64	3.53	33.47	1.58
Scombridae	mackerel & bonito	< 0.01	< 0.01	-	292.60	12.17
Stromateidae	butterfish	0.04	14.49	27.73	218.66	-
Pleuronectidae	flatfishes	4.50	32.17	343.01	28.30	-
Molidae	mola	-	-	298.41	-	-
Other Osteichthyes	other bony fishes	60.87	111.37	154.08	226.09	10.21
Chondrichthyes	sharks and rays	355.60	588.93	743.12	1,082.85	145.99
Totals		1,508.30	4,907.46	5,648.54	15,467.82	213.84

*MBPP values are for Units 3 and 4 only. Units 1 and 2 were not sampled for an entire year and therefore were not included in the annual biomass estimates.

**Values presented are annual averages.

5.3 Summary of CWIS Effects

The impacts of impingement and entrainment on source water populations can be evaluated by estimating the fractional losses to the population attributable to the CWIS. Impingement rates and biomass estimates from the present study provide estimates of impingement losses that can then be translated directly to estimate potential impingement effects on local fisheries (Tables 5-39 and 5-40). Estimated entrainment losses were extrapolated to fishery losses using *FH* and *AEL* estimates. Life history data for computing *FH* and *AEL* were available for only a few taxa and even fewer of those taxa had commercial fishery statistics for the Morro Bay area (Table 5-38).

While the total estimate of impingement for fishes and crabs can be used to obtain a very conservative estimate of fishery losses using statistics for a species such as cabezon, an estimate of total entrainment for fishes that can extrapolated to fishery-sized individuals does not exist. Estimates of the dollar value of impingement losses to individual fish taxa totaled $805 (Table 5-39), while the estimate of the dollar value of entrainment losses to fishes only totaled $246 (based on 2*FH* estimates) because of the absence of *FH* or *AEL* adult estimates of entrainment effects for most taxa (Table 5-38). In addition, many of the fishes that were entrained in highest numbers were small fishes that are not the focus of any recreational or commercial fishery. While we cannot provide a good estimate of the dollar value of entrainment losses to commercial and recreational fisheries, these losses are probably low based on the annual entrainment estimates for these taxa.

For cancer crabs, estimated fishery losses due to entrainment were made using 2*FH* estimates (Table 5-38). The value per kg was estimated using the same methods presented for impingement (Table 5-40). The estimated dollar losses for cancer crabs from both entrainment and impingement totaled $9,582.

The total dollar loss to local fisheries due to the CWIS impacts is low and will be lower still when installation of the new combined-cycle units is complete. The weighted maximum flow rate of the new units will be 38 percent less than the current maximum rate of flow for the existing units.

5.4 Trophic relationships among marine species in Morro Bay

Trophic linkages or "food webs" among marine species in Morro Bay are strongly influenced by the number of component species, high habitat diversity, and daily tidal exchange with the open coast environment. The bay's food web involves interactions among residential species, such as benthic polychaetes and crustaceans that are restricted to tidal mudflats, and transient species, such as leopard sharks that occur along the outer coast and may feed opportunistically within the bay. As in other estuarine systems, photosynthesis forms the base of the bay's food chain through primary production including eelgrass meadows, algal mats, salt marsh vegetation, benthic diatoms, marine phytoplankton, and kelp forests. Several hundred invertebrate species inhabit mudflats, subtidal benthic habitats, fouling communities on pilings, and rock substrates along breakwaters (Tetra Tech 1999), hundreds more comprise the microscopic planktonic community that is contiguous with coastal waters, and at least 70 species of fishes regularly use Morro Bay (Fierstine et al. 1973, Horn 1980, Tetra Tech 1999). For many of these species little is known about their life histories and even less about their trophic interactions. The following discussion presents a qualitative assessment of trophic interactions in Morro Bay, based on available information and understandings, and explains how cooling water withdrawals by the Morro Bay Power Plant may influence food webs in the bay.

Diagrams depicting conceptual food webs are necessarily simplistic, but at the same time can be confusing if more than a few linkages are presented. The relative importance of the component taxa groupings in terms of biomass, energy conversion, or the temporal changes are often not known and cannot be adequately conveyed. However, such diagrams are useful in discussions of potential interactions in a few species and trophic levels that occur in the system. Food web information is usually obtained from gut analyses and predator-prey studies specific to the system being described. The food web diagram depicted in Figure 5-1 partitions the bay's species into major taxonomic groups, and then subdivides each into trophic types, with example species and taxa groups in each level. The feeding interactions between groups are indicated by arrows and point either to a major taxonomic group or sub-group. The power plant interacts as it withdraws planktonic forms, pelagic organisms, and benthic invertebrates through the processes of entrainment and impingement.

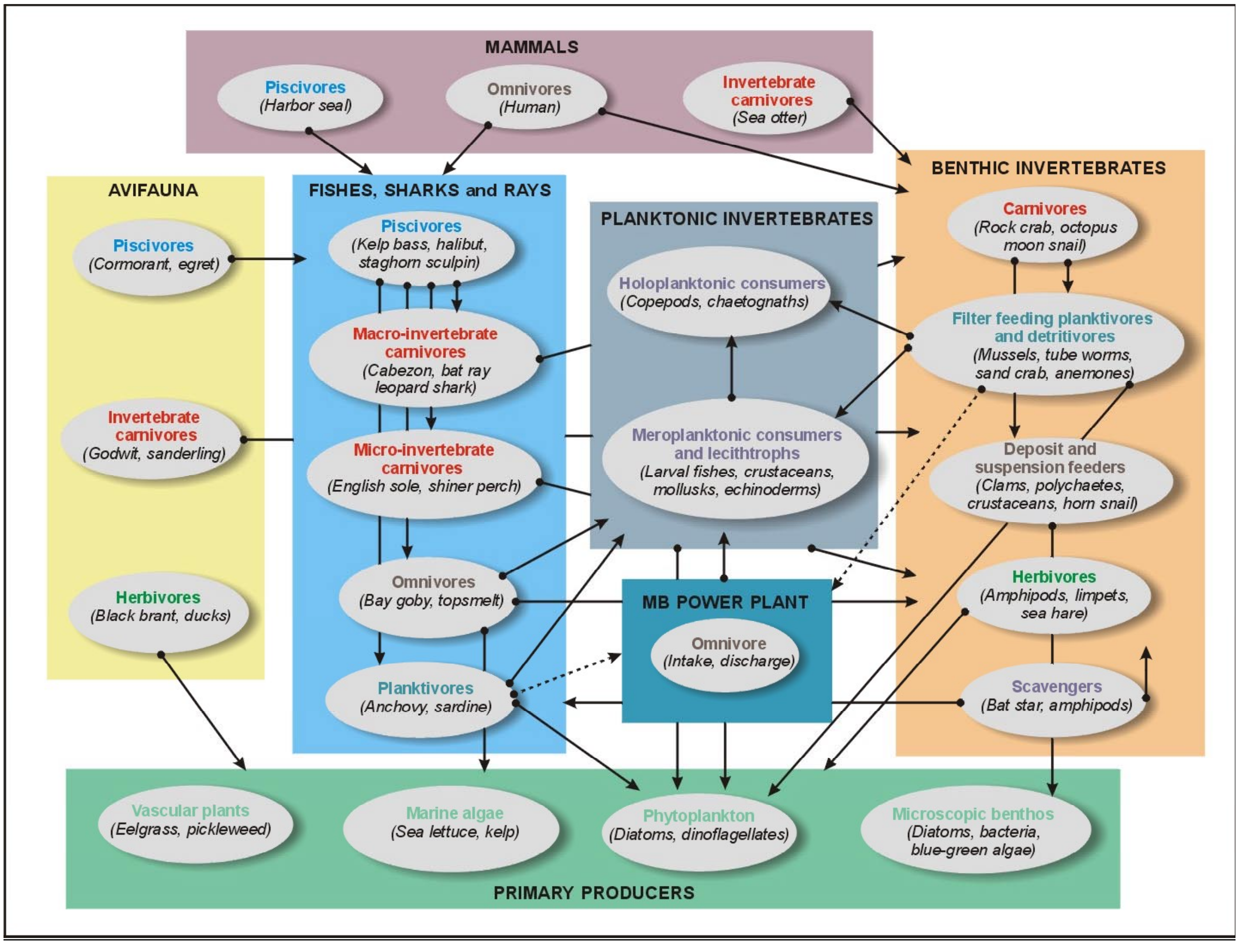

Figure 5-1. Food web identifying major trophic linkages in Morro Bay, including power plant effects. Italicized taxa represent some components of each trophic group within the broad taxonomic groupings.

Food webs are also analyzed by habitat compartments—trophic interactions of species within and among habitats (Pimm 1991). For example, the eelgrass habitat in Morro Bay forms a habitat compartment, and the relationships between component species utilizing eelgrass as food and habitat would be illustrated. While this approach focuses attention on interactions among species in specific habitats, it is less useful when habitats are more or less contiguous and blend into one another, as is the case in a small bay system such as Morro Bay.

Most of the feeding interactions depicted in Figure 5-1 are generalized from studies performed in other estuarine or open coastal systems, as there is little information specifically found in the literature from Morro Bay. Exceptions to this are detailed observational feeding studies on sea otters (F. Wendell, CDFG, pers. comm. 2001) and shorebirds (Boland 1981). However, general feeding types can be inferred from other studies, although the specific proportion of prey items is not known. Barry et al. (1996) and Oxman (1985) studied the trophic ecology of Elkhorn Slough, a central California estuary that has many faunal similarities to Morro Bay. Epifaunal crustacea were the primary prey item for seven of the 18 dominant fishes and elasmobranchs studied, zooplankton and plant material was consumed by five of the species, mollusks and infaunal worms by four of the species, and two predatory species fed mainly on mobile crustacea. The diversity of feeding modes among the resident and immigrant fishes and the rich food sources available within the slough underscored its importance as habitat for juvenile fishes and ocean immigrant species. A detailed trophic spectrum analysis has been conducted on fishes in Elkhorn Slough (Cailliet et al. 1978), a central California estuary that has similarities to the fish fauna in Morro Bay. Stomach contents of 24 common species were grouped into 13 categories comprising mobile fauna, epifauna, infauna, and flora. Trophic spectra were presented by quantifying prey importance in terms of prey numbers and volume in the diets of the various fish species. One conclusion of Cailliet et al. (1978) was that the dietary items of a particular species varied depending upon its habitat and geographical locations within the slough. For omnivorous species in particular, there could be a wide variation in diets among individuals within the same system, and certainly among seasons depending on available prey items.

Physical changes within estuarine systems can affect trophic interactions by altering the abundances of prey resources. Accelerated rates of erosion in Elkhorn Slough changed sediment characteristics over a period of two decades and caused a shift in benthic invertebrate species from assemblages dominated by infaunal worms and mollusks to one dominated by epifaunal crustaceans (Lindquist 1998). The diets of many predatory fishes changed accordingly, although it was not clear how fish population abundances were affected by the shifts in prey availability.

The Morro Bay Power Plant interacts with the Morro Bay food web by entraining and impinging organisms through the cooling water intake system, returning them into the open coastal environment adjacent to Morro Rock (Figure 5-2). Entrained organisms include meroplanktonic eggs and larvae of fishes and benthic invertebrates, and holoplankton such as copepods, that complete their entire life cycle drifting in the water column. Invertebrates, fishes, drift eelgrass, and other organic debris impinged on the intake screening system are also returned to Estero Bay via the discharge canal. All entrained organisms are assumed to undergo 100 percent mortality while transiting the cooling water system, either by physical damage or cropping from biofouling organisms. Barnacles, mussels, and other biofouling organisms that grow within the conduits periodically slough off and are also transported out into the open coastal environment. All of this organic material is returned to a variety of trophic linkages in Estero Bay's food web.

Estero Bay surveys of the discharge and adjacent rocky shoreline habitat have shown a predominance of filter feeding organisms including mussels *Mytilus* spp. and sand tube worms *Phragmatopoma californica*. These species colonize the warmer waters of the discharge and benefit from the increased detrital food supply carried in the current. Skates *Platyrhinoidis triseriata* and rays *Urolophus halleri* occasionally scavenge larger benthic food items in the discharge that are dislodged from the biofouling community. These motile elasmobranch species are not permanent residents of the discharge zone, but can move freely between the discharge zone and the nearshore coastal habitats.

The cooling water discharge flow creates an enhanced supply of organic material that becomes part of the nearshore food web. In the mixing zone beyond the discharge canal, drifting food particles carried offshore are consumed by planktivorous fishes such as topsmelt *Atherinops affinis*, Pacific sardine *Sardinops sagax*, and northern anchovy *Engraulis mordax*. All of these species are widely distributed in coastal waters and can also be particularly numerous in the Morro Bay estuary. Diving birds such as brown pelicans *Pelicanus occidentalis* and cormorants *Phalocorcorax* spp. occasionally feed on aggregations of these smaller fishes in the surf zone adjacent to the discharge. Larger fish predators (striped bass *Morone saxatilis* and white sea bass *Atractoscion nobilis*) are also attracted to the concentrations of smaller fishes, and finally, recreational fishers target these larger predators, thereby extending the local food web to the highest trophic level.

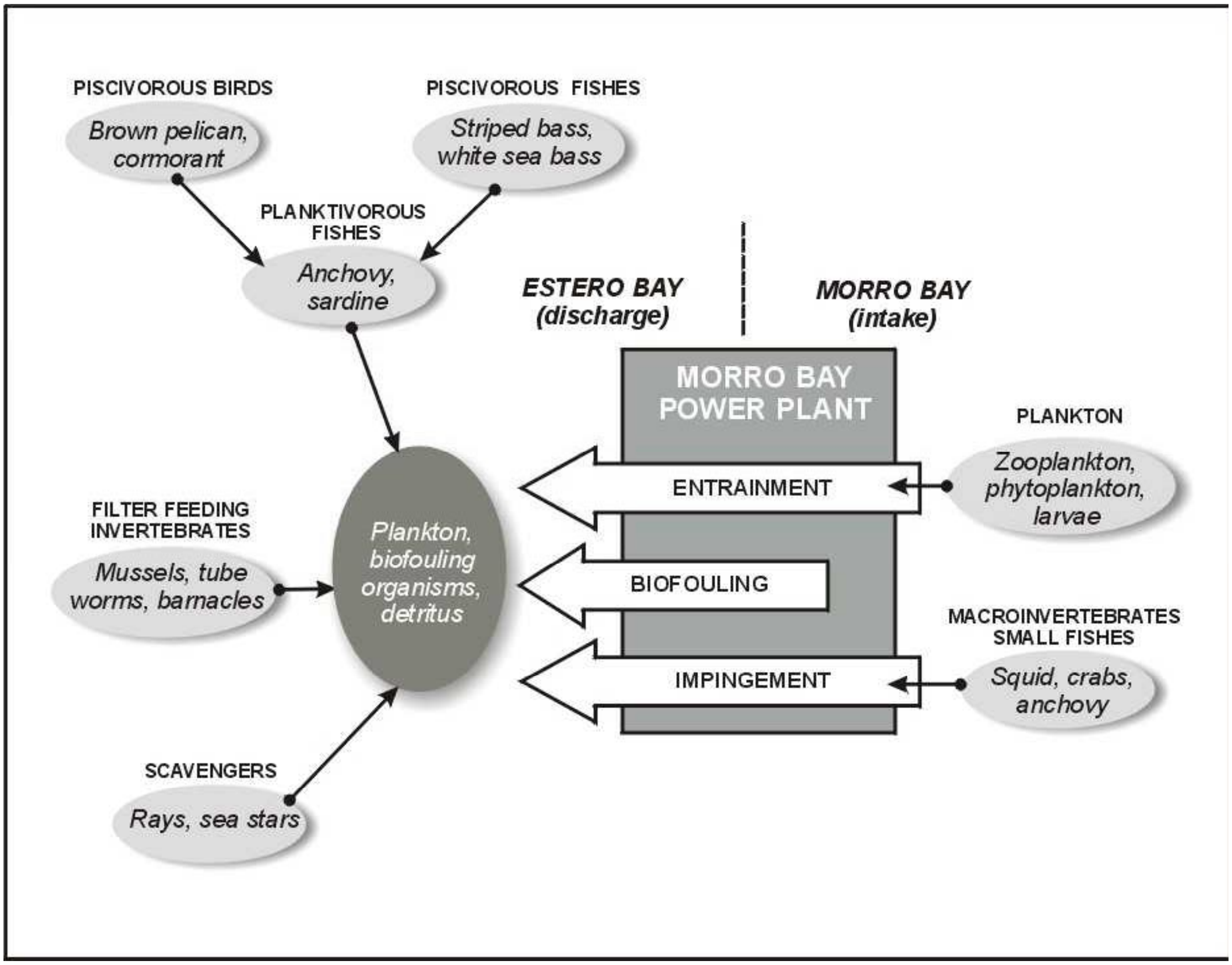

Figure 5-2. Morro Bay Power Plant influence on marine food web resources.

Losses of organisms as a result of power plant entrainment could potentially affect the trophic ecology of Morro Bay through cascading effects in the food web. For example, if a sufficient number of crab or clam larvae were removed from the system, this could lower the abundance of these potential prey items for higher-level predators such as bat rays or sea otters. Because there are no data on prey and predator abundances prior to power plant operation, it is not possible to compare changes in the bay fauna over time with respect to potential power plant effects. Forecasting reductions of adult populations in a single species by modeling their larval losses is one way to approach the problem, but there are considerable uncertainties in predicting the outcomes of recruitment given the complexities of post-settlement biotic interactions. Some predators can also exhibit flexibility in their prey choice, thus compensating for losses of preferred or alternate prey.

The trophic structure in Morro Bay has likely been affected by long-term entrainment and impingement losses, but the nature and magnitude of these changes are not readily apparent. Physical disturbances such as increased turbidity from sediment-laden freshwater inflows, the anthropogenic effects of channel dredging, or biological disturbances resulting from the inadvertent introductions of invasive species may all cause far-reaching changes in the trophic structure of bay systems. When such factors are combined with natural variations in recruitment, any effects of entrainment losses on trophic organization may be obscured.

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