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Post-Impingement Survival and Inferred Maximum Thermal Tolerances for Common Nearshore Marine Fish Species of Southern California

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Abstract.—The effectiveness of a pilot post-impingement fish return program was studied at Los Angeles Department of Water and Power's Scattergood Generating Station during six heat treatments from February 2005 to August 2006. Species-specific total percent survival was computed for all individuals impinged, with an overall survival of 0.4% across all species impinged during monitored heat treatments, ranging from 30.2% for *Paralabrax clathratus* to 0.0% for *Seriphus politus*. Species-specific critical thermal maxima was inferred from surveys of the abundances returned by San Onofre Nuclear Generating Station's highly effective and unique Fish Return System during heat treatments from 2000–2005. Abundant species such as queenfish exhibited low thermal thresholds (15–20°C), while spotfin croaker and barred sand bass became stressed at higher temperatures (25–30°C).

One potential pathway to reduce impingement mortality at generating stations utilizing once through cooling water systems is to return live fish back to the ocean. In southern California, this would be especially useful during heat treatments, during which ambient water temperatures within the cooling water system are raised past 38°C, exceeding the critical thermal maximum for all nearshore marine fish common to the Southern California Bight. At nearly all generating stations within southern California, the most logistically feasible recovery technique is to recover live fish impinged upon the traveling screens used to filter cooling water.

Heat treatments are an operational procedure periodically conducted to control the growth of biofouling organisms that settle out on the walls of the intake conduits (Graham et al. 1977). These growths can restrict water flow to levels that may cause substantial operational and maintenance problems up to, and including, shutting down the station (Graham et al. 1977). These authors determined that water temperatures maintained at greater than 40°C for nearly one hour achieved 100% mortality among biofouling organisms. They further reported that heat treatment duration was inversely proportional to maximum water temperature necessary to achieve better than 95% mortality of the biofouling organisms. Lastly, they concluded that minimal environmental impacts to nearby marine resources (fish populations, water quality, etc.) were produced by short, high temperature (> 40°C) heat treatments rather than longer, lower temperature treatments. At many coastal southern California generating stations with enclosed forebays this procedure can result in a substantial portion of the total annual impingement mortality.

Studies of survival of juvenile and adult marine organisms after entrapment in once through cooling water systems have largely been limited to the physical stress caused by impingement alone on Atlantic and Gulf Coast species (King et al. 1977, Muessig et al.

1988, McLaren and Tuttle 2000), with limited attention to the associated stressors of elevated water temperatures. Much of the work conducted on Pacific species was done at San Onofre Nuclear Generating Station (SONGS) in San Clemente, California, in relation to the operation of their novel fish return system (Love et al. 1989). The SONGS fish return system (FRS) limits the physical stressors encountered by the entrapped organisms by providing a return mechanism without interacting with the traveling screens, effectively eliminating impingement for those organisms that were routed through the FRS. While proving an effective means of reducing the impingement mortality, its applicability to existing once through cooling water systems is limited due to high costs and engineering constraints. SONGS Units 2 and 3 were initially constructed with the fish return system integrated into the overall design (R. H. Moore, MBC Applied Environmental Sciences, personal communication). Continued monitoring of the FRS immediately preceding heat treatments provided baseline insight into the thermal tolerances of various fish species common to the Southern California Bight.

This pilot study investigated the applicability of collecting live fish from the traveling screens at Scattergood Generating Station in Los Angeles, California during heat treatments as a potential means of reducing impingement mortality. Furthermore, critical thermal maxima for common coastal marine species were inferred based on analyses of SONGS FRS surveys.

Materials and Methods

Post-Impingement Survival

During routine monitoring of six heat treatments from February 2005 to August 2006 at Scattergood Generating Station (SGS), live fish were collected from traveling screens. Traveling screens at SGS are steel, 9.5-mm square mesh, which are continuously rotated during heat treatments. Housings for the traveling screens at Units 1 and 2 were opened, allowing for visual inspection and collection of animals off of the traveling screens. The housings at Unit 3, however, were sealed leaving the traveling screens relatively inaccessible. All traveling screens were 1.8-m wide and extended 7.2-m below ground level into the forebay.

Collections began at the start of the heat treatment when forebay water temperatures were at ambient levels and concluded when temperatures exceeded 35°C, as reported by generating station staff. Fish were collected by hand from the screens. After being removed from the traveling screen, all fish were held in buckets that had been filled with seawater prior to the start of the heat treatment. After the heat treatment concluded, all live fish were transported to the SEA Lab and transferred to holding tanks on a flow-through seawater system held at ambient conditions.

The SEA Lab maintained collected fish at their facility in Redondo Beach, California. Daily observations were made to determine the health (live or dead) of each collected organism per 24-hour time block for 144-hrs beyond the day of collection. Mortalities were recorded per 24-hr block. Abundances for total collected, daily mortality, total survival, and total impinged were reported by species (and fish family). Percent survival was derived for both the individuals collected and the total impinged abundance for each species and cumulatively across all species. Species-specific analysis was limited to those with greater than 100 individuals impinged during the course of the study. Although lengths were recorded for the recovered individuals, they could not be assigned to specific mortalities, as fish were not marked for identification.

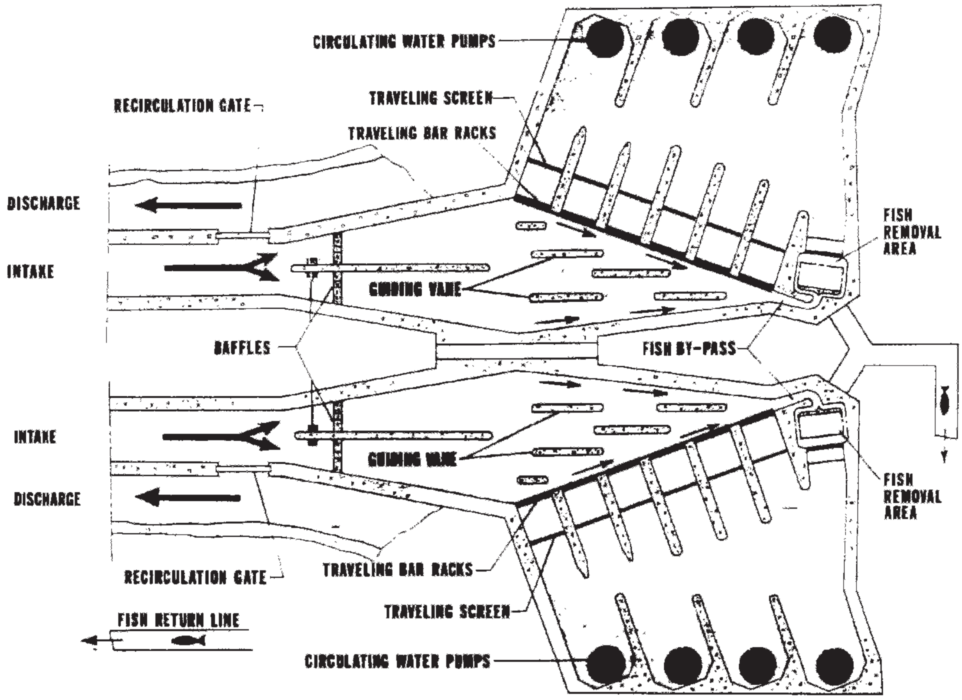

Fig. 1. San Onofre Nuclear Generating Station forebay depicting fish removal area (Fish Return System).

Inferred Critical Thermal Maxima

Operational procedures at SONGS for heat treatments include the "fish chase", which was designed to usher living fish within the forebay into a holding area where they can be lifted out and deposited into a dedicated discharge line (Figure 1). The design of the forebay for the FRS included guiding vanes that, in concert with the angled traveling screens, created a pressure differential that can be detected by the fish and ultimately direct them to the fish removal area (Love et al. 1989). This was accomplished by slowly raising the forebay water temperature while biologists monitor the FRS. Although it was expected that thermal gradients exist throughout the forebay as water temperature was raised, it was assumed that no areas of relatively cool water were present in which fish may find refuge. It was believed that the strong, unidirectional flow created by the circulating water pumps sufficiently mixed the waters within the forebay to greatly limit the extent of cool water refuges.

As fish became stressed due to the increased water temperature, their ability to swim against the cooling water flow diminished, increasing their likelihood of collecting in the fish removal area (Figure 1). The relative abundance and observed health of fish within the FRS elevator served as a behavioral indicator of inferred critical thermal maxima. Fish were lifted out of the SONGS forebay by a steel tray elevator system that raised the fish in a large pool of water up to a point at which they were deposited in a discharge flume filled with seawater at the ambient temperature of the coastal waters. Prior to depositing the fish, each elevator lift was visually inspected, organisms identified, and estimated abundance recorded. The procedure was continued until no live fish were present within the elevator. A more thorough description of the FRS is available in Love et al. (1989).

Recorded abundance, by species, per forebay water temperature, was reviewed for the period 2000–2005. Forebay water temperature was continuously recorded in the station control room from sensors located within the cooling water intake system. Data across all years was pooled and forebay water temperature rounded to the nearest integer. The percentage of the total abundance by species was derived for each temperature interval, with the 20 most abundant species examined. Data for the 15 most abundant species observed between 2000–2005 in the SONGS data set was included in the analysis. Similarities in species-specific responses to increasing water temperature were graphically derived through hierarchical clustering analysis. Proportional abundance by temperature block was used to calculate the inter-entity distance (dissimilarity) matrix. Euclidean distance (Clifford and Stephenson 1975) was used as the measure of dissimilarity. A cluster diagram was drawn based on these dissimilarities. Species groups were assigned to each unique cluster. Proportional abundance per species group was derived and plotted against their representative temperature block. Pearson product correlation was used to test the relationship between the forebay water temperature and the proportional abundance for each species group defined by cluster analysis.

During three heat treatments at SGS in 2005 (16 February, 6 April, 13 June) water temperature within the forebay was continuously monitored with a data logger positioned at the seaward edge of the forebay. This side of the forebay was subjected to warmer water temperatures prior to the rest of the forebay, due to its closer proximity to the intake/discharge tunnel openings. Circulation patterns and temperature mixing within the forebay was not measured. It was assumed that hydrodynamic forces previously described for the SONGS forebay were mixing the seawater in the SGS forebay. Deposition of impinged fish into the northwest basket was sampled every five minutes. Sampling consisted of filtering the effluent stream with a one-quarter inch mesh dipnet for one minute. Abundance per time interval was recorded and later plotted against water temperature profiles as reported by the data logger.

Results

Fish Return Program

A total of 464 individual fish, or 0.5% of all impinged fish, were collected alive representing 38 species from 19 families during six heat treatments monitored at SGS (Table 1). During these heat treatments, a total of 101,122 individual fish were impinged. Queenfish (*Seriphus politus*) was the most frequently observed species during the six impingement surveys, overall, with 31,957 individuals. Three additional species collected alive were represented by greater than 3,000 impinged individuals, including 5,525 topsmelt (*Atherinops affinis*), 4,380 white croaker (*Genyonemus lineatus*), and 3,721 walleye surfperch (*Hyperprosopon aregenteum*).

Walleye surfperch (58 individuals) was the most abundant species collected alive. In addition, 48 topsmelt, 45 kelp bass (*Paralabrax clathratus*), 44 bat rays (*Myliobatis californica*), and 30 black perch (*Embiotoca jacksoni*) were collected alive during impingement sampling (Table 1). Less than 30 individuals were collected alive from each of the remaining species. Of these, only topsmelt and walleye surfperch were included among the five most abundant impinged species overall.

Of the fish collected during the six heat treatments and held for observation, a total of 383, or 82.5%, survived the holding period, which equates to 0.4% of all impinged fish

Table 1. Hourly survival of fish species collected during heat treatments at Scattergood Generating Station, February 2005 to August 2006.

Species	Number Collected	Mortality per Hour Interval Since Collection 0	24	48	72	96	120	144	Total Survival	% Survival	Total Impinged	% Total Survival	% of Total Imp. Collected
Hyperprosopon argenteum	58	4	1	2	-	-	1	-	50	86.2	3,721	1.3	1.6
Atherinops affinis	48	1	3	-	-	-	-	-	44	91.7	5,525	0.8	0.9
Paralabrax clathratus	45	-	-	-	-	-	-	-	45	100.0	149	30.2	30.2
Myliobatis californica	44	15	-	2	-	-	-	-	27	61.4	164	16.5	26.8
Embiotoca jacksoni	30	2	1	-	-	-	-	-	27	90.0	175	15.4	17.1
Genyonemus lineatus	26	2	1	1	-	-	-	-	22	84.6	4,380	0.5	0.6
Atherinopsis californiensis	26	2	-	1	-	-	-	1	22	84.6	930	2.4	2.8
Pleuronichthys ritteri	21	2	2	1	-	-	-	-	16	76.2	100	16.0	21.0
Platyrhinoidis triseriata	19	-	2	-	1	-	-	-	16	84.2	38	42.1	50.0
Urobatis halleri	18	-	-	-	-	-	-	-	18	100.0	52	34.6	34.6
Paralabrax nebulifer	14	1	-	-	-	-	-	-	13	92.9	156	8.3	9.0
Scorpaena guttata	13	-	-	-	-	-	-	-	13	100.0	77	16.9	16.9
Seriphus politus	11	7	3	-	-	-	-	-	1	9.1	31,957	0.0	0.0
Rhacochilus toxotes	11	-	-	1	1	-	-	1	8	72.7	68	11.8	16.2
Sebastes auriculatus	10	-	-	-	-	-	-	-	10	100.0	44	22.7	22.7
Chromis punctipinnis	7	-	-	-	-	-	-	-	7	100.0	131	5.3	5.3
Cheilotrema saturnum	7	-	1	-	-	-	-	-	6	85.7	91	6.6	7.7
Hypsoblennius gilberti	7	-	-	-	-	1	1	-	5	71.4	48	10.4	14.6
Medialuna californiensis	6	1	1	-	-	-	-	-	4	66.7	16	25.0	37.5
Cymatogaster aggregata	5	2	-	-	-	-	-	-	3	60.0	428	0.7	1.2
Atherinopsidae	5	1	1	1	-	1	1	-	-	0.0	266	0.0	1.9
Atractoscion nobilis	5	-	-	-	-	-	-	-	5	100.0	23	21.7	21.7
Heterostichus rostratus	5	-	-	-	-	-	-	-	5	100.0	22	22.7	22.7
Paralichthys californicus	4	1	-	-	-	-	1	-	2	50.0	13	15.4	30.8
Menticirrhus undulatus	3	-	-	-	-	-	-	1	2	66.7	62	3.2	4.8
Scorpaenichthys marmoratus	3	-	-	-	-	1	-	-	2	66.7	4	50.0	75.0
Oxyjulis californica	2	-	-	-	-	-	-	-	2	100.0	21	9.5	9.5
Phanerodon furcatus	1	-	-	-	-	-	-	1	-	0.0	158	0.0	0.6
Rhacochilus vacca	1	-	-	-	-	-	-	-	1	100.0	20	5.0	5.0
Sebastes paucispinis	1	-	-	-	-	-	-	-	1	100.0	16	6.3	6.3
Brachyistius frenatus	1	-	-	-	-	-	-	-	1	100.0	6	16.7	16.7
Oxylebius pictus	1	-	1	-	-	-	-	-	-	0.0	4	0.0	25.0
Torpedo californica	1	-	-	-	-	-	-	-	1	100.0	2	50.0	50.0
Parophrys vetulus	1	-	-	-	-	-	-	-	1	100.0	1	100.0	100.0
Pleuronichthys guttulatus	1	-	-	-	-	-	-	-	1	100.0	1	100.0	100.0
Sebastes atrovirens	1	-	1	-	-	-	-	-	-	0.0	1	0.0	100.0
Sebastes chrysomelas	1	-	-	-	-	-	-	-	1	100.0	1	100.0	100.0
Stereolepis gigas	1	-	-	-	-	-	-	-	1	100.0	1	100.0	100.0
Total all species	464	41	18	9	2	3	4	4	383	82.5	101,122	0.4	0.5

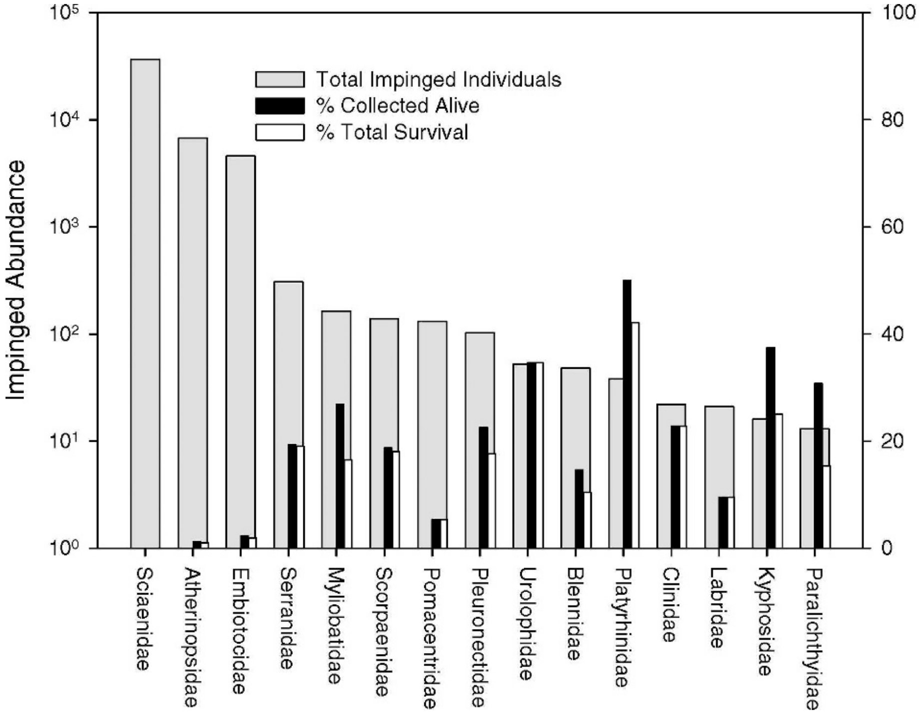

Fig. 2. Log of impinged abundance, total percent collected alive, and total percent survival during heat treatments by fish family observed at Scattergood Generating Station.

(Table 1). Survival of individuals from species with a minimum of 100 individuals impinged was highly variable. Overall survival was generally inversely proportional to total impingement. The highest overall survival rate was recorded for kelp bass, with 30.2% survival, or 45 individuals surviving out of 149 individuals impinged. Other species that exhibited relatively strong heat treatment survival patterns include bat ray (16.5%), spotted turbot (*Pleuronichthys ritteri*) (16.0%), and black perch (15.4%), but all three species were impinged in relatively low abundances, each less than 0.2% of the total impinged abundance. Five additional species survived in proportions ranging from 1.0 to 10.0% of their species-specific impinged abundance.

Three fish families (Embiotocidae, Atherinopsidae, and Sciaenidae) represented the majority of all impinged fish (Figure 2). Highly abundant families exhibited little to no survival, while less abundant families were more influenced by the recovery efforts. Occasionally, there was considerable intra-familiar variation, such as with sciaenids. Virtually all queenfish and white croaker perished over the course of the heat treatment. A greater proportion of California corbina (*Menticirrhus undulatus*) survived through the holding period, while greater than one-fifth of all impinged white sea bass (*Atractoscion nobilis*) survived. Each of the latter two species was infrequently impinged, represented by a total of 62 and 23 individuals, respectively (Table 1).

Analyses of the collected individuals illustrate the various species-specific, post-impingement latent survivability. Latent post-impingement survival for the 15 species with 10, or greater, individuals collected alive ranged from 9.1% for queenfish to 100% for four species, including kelp bass, round stingray (*Urobatis halleri*), California

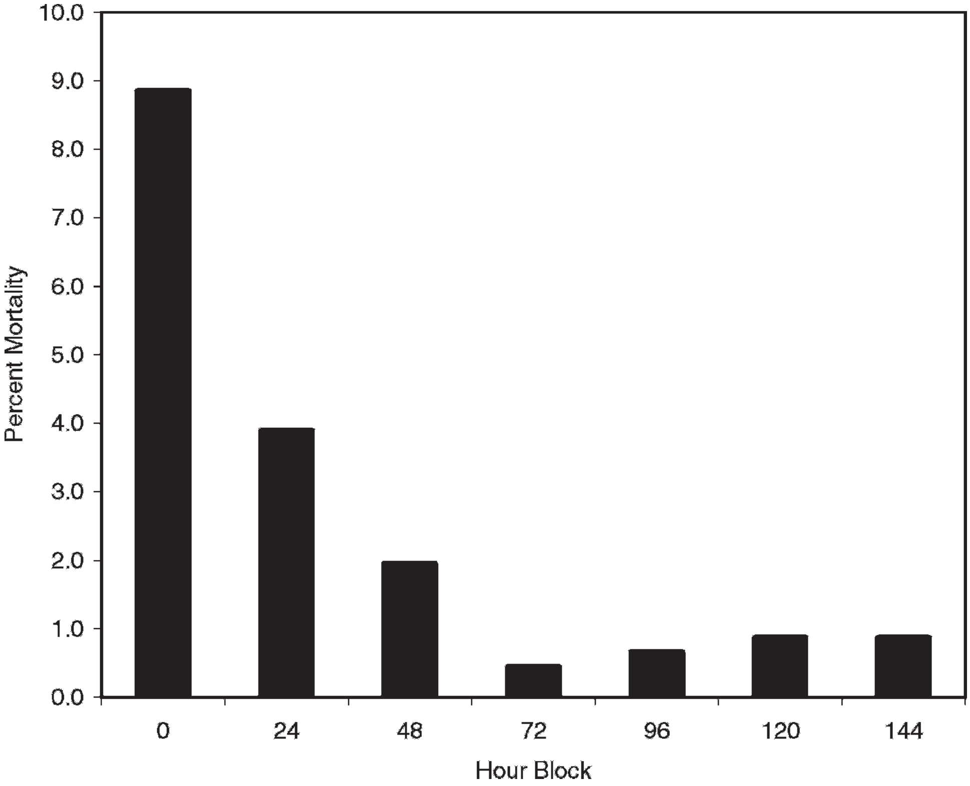

Fig. 3. Percent mortality by hour block for fishes collected during heat treatments at Scattergood Generating Station.

scorpionfish (*Scorpaena guttata*), and brown rockfish (*Sebastes auriculatus*) (Table 1). For the collected individuals, peak mortality occurred within the first 48-hrs, with nearly 9% perishing within the first 24-hrs (Figure 3). This figure was greatly influenced by the high mortality of bat rays, followed by nearly 70% of all queenfish perishing within the first 24-hrs (Table 1). The overall survivability of queenfish was poor, with one out of 11 individuals collected surviving the holding period. Overall, 11 out of 15 species with greater than 10 individuals collected exhibited greater than 80% latent survival rates.

Inferred Critical Thermal Maxima

The principle stressor on fishes observed during heat treatments was the forebay water temperature (designed to exceed 38°C), which interferes with the metabolic processes of most fish (Helfman et al. 1997). Although all fishes entrapped within the enclosed forebay were subjected to these conditions, notable differences have been observed with regards to their varying thermal tolerances. Species-specific abundance within the FRS elevator was indicative of the relative composition of the entrapped assemblage, as it has been anecdotally noted that various species arrive in the elevator area in sequential stages related to water temperature (R. H. Moore, MBC Applied Environmental Sciences, personal communication).

Fish abundance by 1°C temperature interval illustrates a wide-ranging distribution among the 29 most abundant species over the period 2000–2005 (Table 2). Of these, the

Table 2. Proportional abundance by 1° C temperature block for the 20 most abundant species observed at SONGS FRS, 2000–2005.

	Forebay Water Temperature (C)																				
Species	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	38
Anisotremus davidsonii	-	0.6	0.4	0.1	4.5	4.3	1.5	3.1	1.4	3.1	2.2	8.6	10.0	8.1	7.7	13.1	17.8	12.2	1.1	0.1	0.2
Atherinops affinis	-	47.5	19.7	0.3	7.6	7.7	6.7	2.6	0.9	1.5	2.5	0.5	0.3	1.4	0.7	-	0.2	-	-	-	-
Atherinopsis californiensis	0.2	2.1	50.3	6.0	3.7	6.2	15.7	4.5	0.3	4.8	0.7	2.6	1.3	0.7	0.6	0.2	0.1	0.1	-	-	-
Cheilotrema saturnum	-	-	-	-	2.2	3.7	-	2.2	20.6	2.9	0.7	-	2.2	4.4	7.4	14.0	19.1	19.9	0.7	-	-
Embiotoca jacksoni	-	-	3.7	6.8	2.1	15.3	-	3.7	0.5	4.2	1.6	7.9	14.7	6.3	13.2	11.6	7.4	1.1	-	-	-
Engraulis mordax	0.1	1.7	10.9	1.0	6.5	20.3	3.5	21.5	7.1	17.1	4.5	2.8	1.8	1.0	0.2	0.1	0.0	0.0	-	-	-
Genyonemus lineatus	-	-	50.6	3.7	8.3	13.1	5.9	1.5	-	6.4	-	0.2	0.1	5.0	4.7	0.6	-	-	-	-	-
Hermosilla azurea	-	0.5	-	-	-	1.0	0.1	1.2	2.1	3.3	-	5.5	8.5	2.0	12.5	14.2	29.9	18.5	-	-	0.8
Hyperprosopon argenteum	0.9	1.3	26.9	6.0	5.3	5.3	8.2	3.6	1.1	11.5	2.7	6.5	15.6	3.8	0.9	0.3	0.3	-	-	-	-
Paralabrax clathratus	-	-	-	-	0.6	3.6	1.2	4.8	2.4	5.4	3.6	1.2	13.8	13.8	18.6	14.4	10.2	3.0	3.6	-	-
Paralabrax nebulifer	-	-	1.4	0.5	1.5	0.7	0.7	1.6	1.8	3.1	2.1	4.0	8.1	8.8	19.8	14.3	16.8	11.9	2.8	0.1	-
Peprilus simillimus	-	-	67.9	3.4	8.1	0.2	0.2	11.7	-	2.7	0.8	2.9	1.7	-	0.5	-	-	-	-	-	-
Phanerodon furcatus	-	10.2	5.1	5.4	0.3	13.9	1.0	3.1	1.0	17.3	10.5	16.0	2.0	7.5	4.4	-	2.0	-	-	-	-
Roncador stearnsii	-	0.1	0.0	0.2	1.1	5.4	1.1	0.7	0.2	3.9	0.3	2.5	14.7	41.9	11.6	9.1	6.1	1.2	-	-	-
Sardinops sagax	-	12.4	13.7	28.9	12.9	11.3	13.6	0.5	1.0	1.6	1.6	1.2	0.6	0.3	0.3	0.1	0.2	-	-	-	-
Scorpaena guttata	0.9	-	2.8	4.7	1.9	2.8	1.9	0.9	5.7	14.2	0.9	8.5	15.1	13.2	12.3	5.7	4.7	3.8	-	-	-
Seriphus politus	1.0	2.6	36.9	12.9	8.6	10.4	1.7	8.9	1.8	9.4	1.7	1.9	1.2	0.3	0.5	0.4	0.0	0.0	-	-	-
Trachurus symmetricus	-	-	-	-	-	37.0	18.3	4.6	0.7	16.7	3.1	11.2	1.9	0.7	2.3	-	1.1	2.1	0.4	-	-
Umbrina roncador	-	0.1	0.5	0.3	3.0	3.2	1.4	2.7	2.8	5.1	1.9	7.0	17.0	12.4	15.0	10.3	9.0	7.3	0.6	0.2	0.1
Xenistius californiensis	-	9.0	1.5	0.2	1.4	3.2	6.5	6.9	8.4	5.9	4.4	6.6	21.8	7.3	4.7	2.2	6.9	2.8	0.3	-	-

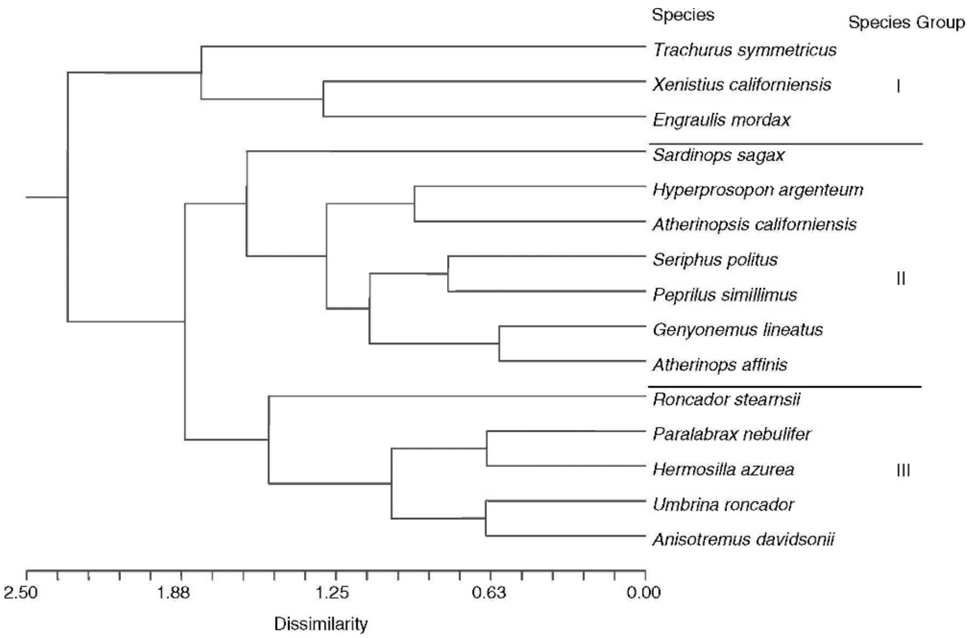

Fig. 4. Results of the cluster analysis for the fifteen most abundant species observed during FRS surveys at SONGS, 2000–2005, based on proportional abundance and forebay water temperature relationships.

relationship between the 15 most abundant species by the forebay water temperature-elevator abundance interaction was visualized through cluster analysis (Figure 4). Based on the dissimilarity coefficients, three species groups were delineated. Group I includes jack mackerel (*Trachurus symmetricus*), salema (*Xenistius californiensis*), and northern anchovy (*Engraulis mordax*) that were relatively cosmopolitan with regards to the relationship of temperature and abundance (Figure 5) and showed no direct correlation to forebay water temperature ($r = 0.41$, $p = 0.07$). The proportional abundances of Group I species peaked at 20°C. Group II included many of the more abundant species observed in impingement surveys across the Southern California Bight (MBC 2005a, MBC 2005b), including queenfish, walleye surfperch, jacksmelt (*Atherinopsis californiensis*), Pacific sardine (*Sardinops sagax*), Pacific pompano (*Peprilus simillimus*), white croaker, and topsmelt (Figure 4). Proportional abundances for Group II species peaked at 15°C (Figure 5) and exhibited a significant correlation with temperature ($r = 0.57$, $p < 0.01$).

Species with higher critical thermal maxima comprised Group III, namely zebraperch (*Hermosilla azurea*), spotfin croaker (*Roncador stearnsii*), barred sand bass (*Paralabrax nebulifer*), yellowfin croaker (*Umbrina roncador*), and sargo (*Anisotremus davidsonii*) (Figure 4). Proportional abundances were consistently higher between 25°C and 30°C than at the remaining temperatures (Figure 5). Group III did not exhibit a significant correlation with water temperature ($r = 0.36$, $p = 0.11$).

Although relative thermal tolerances, based on the SONGS FRS data, was consistent within most fish families, e.g. Serranidae, Embiotocidae, etc., some substantial variation was present within select families, most notably the sciaenids (Table 2). Queenfish and white croaker both reached their respective peak abundances at 15°C while yellowfin

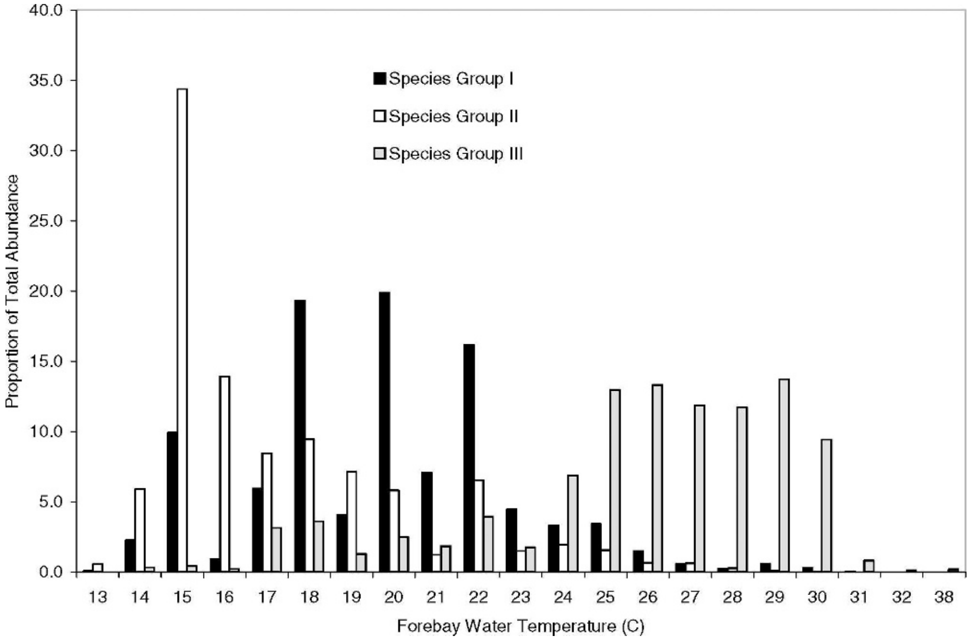

Fig. 5. Total proportional abundance by forebay water temperature for each species group observed during FRS surveys at SONGS, 2000–2005.

croaker and spotfin croaker proportional abundances peaked at 25°C and 26°C, respectively.

In sampling designed to emulate the SONGS fish chase, three heat treatments were monitored for total fish abundance by temperature block at SGS (Figure 6). Abundances of impinged fish nearly doubled on each survey after the forebay water temperatures reached 29°C, as recorded by the data logger. Queenfish and topsmelt comprised the majority of each sample during these heat treatments.

Discussion

Heat treatments at southern California power plants with enclosed forebays contribute a substantial portion of the total impingement mortality recorded. As a part of their efforts to examine ways of reducing fish impingement mortality, a pilot fish return program was evaluated at SGS. The pilot program indicated an overall low survival, with only 0.4% of all fishes impinged during the monitored heat treatments surviving the 144-hr holding period. Furthermore, these data suggest the overall efficacy of this type of return program was highly species-specific. Hearty species such as kelp bass exhibited higher survivorship over the holding period, which corresponded to a 30.2% reduction in their species-specific impingement mortality, while less hearty species, such as queenfish, rarely survived the holding period.

Mortality among all collected species during the holding period was highest within the first 24-hrs after being impinged, before declining rapidly to the 72-hr block, where mortality reached a low of 0.4%, and remained below 1.0% for the remainder of the holding period. Generally, fish species with greater maximum thermal tolerances, such as kelp bass, were collected alive in proportionally greater abundances. These species individually represented less than 0.2% of the total impingement. Of those species

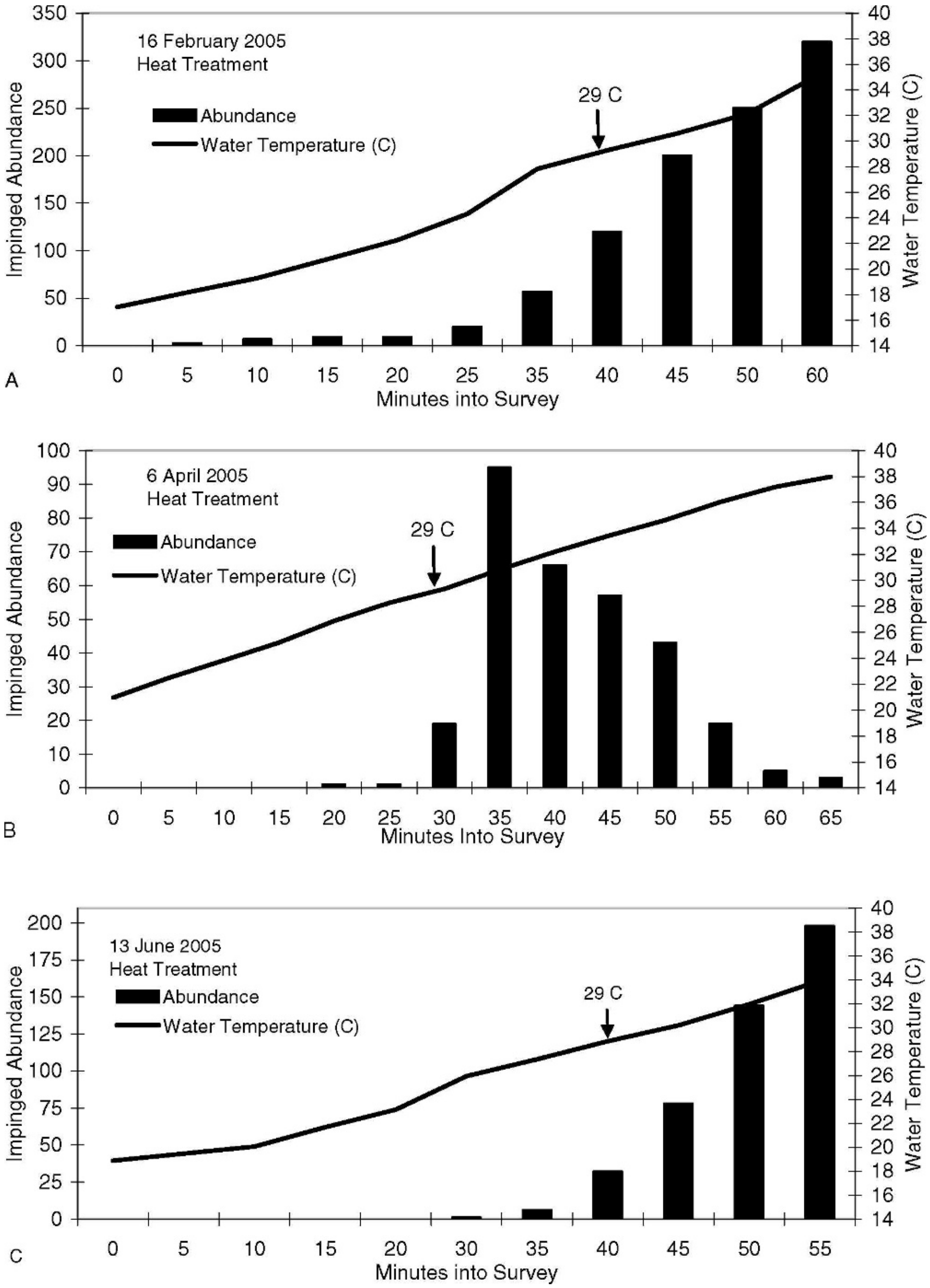

Fig. 6. Impinged abundance and forebay water temperature for three heat treatments at SGS, A) 16 February 2005, B) 6 April 2005, C) 13 June 2005.

representing greater than 1.0% of the total impinged abundance, only four were collected alive off the traveling screens at SGS. Walleye surfperch was the only member of this group that exhibited greater than 1.0% overall survival. Queenfish was the most abundant species impinged, but less than 0.1% were collected alive and less than 10% of those collected alive survived the holding period.

At SONGS, the FRS provided insight as to the thermal tolerances of common nearshore marine fish. Exact values for critical thermal maxima (CTM) and lethal temperature (LT) could not be directly quantified with the FRS due to the design of the forebay at SONGS, which precludes observations consistent with previous studies of thermal tolerance in fish (Tsuchida 1995, Rajaguru 2002). Typical studies determine the CTM by the fish loss of righting response (LRR), which is typified by an observable loss of equilibrium. The construction of the forebay at SONGS precludes this. In contrast, this study examined the abundances of fishes that were presumably stressed by the heated water within the forebay and subsequently concentrated in the fish removal area. Additionally, the LT cannot be fully quantified because moribund fishes at SONGS are frequently collected by the traveling screen structures rather than collecting in the fish removal area.

Cluster analysis of the 15 most frequently observed species in the SONGS FRS revealed three groups, with definitive intra-family variation, based on their proportional abundances by temperature. The highly abundant species with biogeographic ranges that extend into the Oregonian Province (Love et al. 2005, Horn et al. 2006) principally comprised Groups I and II, exemplifying their affinity for cooler water with higher proportional abundances at lesser forebay water temperatures and near absences at the higher temperatures. Meanwhile, Group III species, which were principally San Diegan Province species (Love et al. 2005, Horn et al. 2006), exhibited substantially greater maximum thermal tolerances during the FRS surveys.

The abundance to forebay water temperature relationship observed during three SGS heat treatments indicates dramatically increased abundances at temperatures less than 29°C. During these surveys at SGS, queenfish was the most abundant species, followed by topsmelt, both of which were included in FRS Group II. Based on the FRS analyses, both species have similar cooler water affinities and inferred critical thermal maxima of approximately 15°C, which is consistent with the marked increases in impinged abundance observed circa 29°C at SGS. The exact temperature at which the fish were overcome at SGS was undetermined due to the size and volume of the forebay. This was further confounded by the variable time required for a fish to be carried out of the forebay by the traveling screens, washed along the collection trough, and finally deposited in the sampling basket. These variables all contribute to the unreliability in determining the critical thermal maxima, based on SGS data, but does confirm that water temperatures within a range preceding 29°C was incapacitating for the entrapped fish, namely queenfish and topsmelt.

The SGS fish return program did carry inherent variables that could not be completely accounted for, namely handling stress and injury resulting from physical impingement upon the traveling screen and physiological stress resulting from heating the surrounding seawater in excess of 38°C. The handling stress was unaccounted for, and may have been considerable, but the physiological stress was partially addressed by the associated analysis of the SONGS FRS surveys. It was assumed, but untested, that the stresses caused by handling may exceed those that may be experienced in transit through a dedicated return conduit, similar to that which was used at SONGS.

Love et al. (1989) examined the survivorship of fish returned to the ocean at ambient temperature via the FRS at SONGS Units 2 and 3. During these trials fish were diverted into a net holding pen moored on the seafloor upon exiting from the return conduit. A reference station to determine experimental variation was constructed by corralling fish into a similar net pen located near the return conduit off San Onofre. One significant difference between Love et al. (1989) and the current investigation was the added handling and impingement stress each animal encountered in the current study that was not present during the SONGS experiments. During the SONGS studies water temperatures were maintained at ambient levels as the FRS was operated, thereby removing the physiological stress of the heated water as well as the handling/impingement stress. Fish were held in their respective net pens *in situ* for 96-hrs to test for latent mortality.

Northern anchovy was the most abundant species in the Love et al. (1989) study, exhibiting relatively high survival rates for both units, but none were colleted alive during the current study at SGS, despite substantial impinged abundances. Queenfish was the second most abundant species included in the Love et al. (1989) study. In their experimental treatments, they recorded 31.6 and 54.1% survival for queenfish discharged by the SONGS Units 2 and 3 FRS, respectively, while 78.8% of the reference site individuals survived. These values were substantially higher than was recorded during the current investigation, which can be attributed to the increased stressors encountered by queenfish in the current study. The physical trauma caused by impingement, in addition to the elevated water temperatures may have worked in concert to greatly reduce impingement survivability, as indicated by the relatively low percentage of impinged individuals that were collected alive. Although individual fish were not identified so as to coordinate fish lengths and survivability in the SGS study, high survival variability in relation to fish size was observed in queenfish by Love et al. (1989).

White croakers were also collected in high enough abundances during the SONGS study to warrant further analysis (Love et al. 1989). The authors reported latent survival rates for white croaker similar to that of queenfish, 49.5% for Unit 2 and 25.0% for Unit 3. The latent survival for individuals collected alive in the current study exceeded that reported by Love et al. (1989), with 84.6% of all individuals collected alive surviving the holding period, but with substantially smaller sample sizes than those used by Love et al. (1989). In the previous SONGS study, 93% and 39% (1984 and 1985, respectively) of all white croaker entrapped in the cooling water system were returned alive by the FRS while less than 1% of those impinged at SGS were collected alive. Despite the differences in latent survival, these data indicate that substantially more white croaker were returned to the coastal waters alive by SONGS than was possible at SGS.

Overall, the latent survivability observed in the current study compares favorably to the prior study at SONGS, although the overall entrapment survival was greatly reduced at SGS. During the study at SONGS, a minimum of 75.1% of all annually entrapped fish was returned to the nearshore waters. Three of the species directly analyzed; northern anchovy, queenfish, and white croaker, were returned in highly variable percentages (Love et al. 1989). During the current study, approximately 0.4% of the fishes entrapped in the cooling water system at SGS survived through the holding period. Although not all fish returned at SONGS survived, the associated survival data indicated well above 50% of all individuals, for most species, survived the encounter.

No other studies of fish survival at coastal power plants have been published in southern California, but work has been published from the Atlantic Coast. King et al.

(1977) examined the survival of adult Atlantic tomcod (*Microgadus tomcod*) at ambient temperature at Roseton and Danskammer Point Generating Stations located along the Hudson River. Their studies determined proportionally high survivorship among impinged individuals. Initial survival ranged from 89 to 96% at both stations, while latent survival after an 84-hr holding period ranged from 71 to 86%. The researchers further noted that impingement survival was greatest among fishes collected while the traveling screens were in continuous operation, with inversely proportional increases in mortality as the length of time the screens remained stationary increased.

Muessig et al. (1988) conducted similar studies at Bowline Point and Danskammer Point Generating Stations, also located on the Hudson River. They observed a wider range of impinged species, and noted a relatively high initial impingement survival of greater than 80%. Latent survival of impinged individuals varied widely, with several highly abundant species exhibiting better than 50% survivorship, while alewives (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) displayed very high mortality rates after a four-day holding period. Neither King et al. (1977) or Muessig et al. (1988) incorporated high water temperatures, as would occur during heat treatments, in their study design. It is unknown what effect, if any, increased water temperatures may have on the overall survivability of these test species, although it is assumed the increased stress would increase the overall mortality.

A similar lack of relevant data was available regarding thermal tolerances for marine fishes common to the Southern California Bight. Ehrlich et al. (1979) examined thermal behavioral responses in several commonly impinged fish species. Although it should be noted that most of the species included in this analysis were among those that exhibited higher survival rates during the current SGS fish return study. They found that adult black perch immediately searched out an area in their test tank with a mean water temperature of 18°C, which is well below the inferred critical thermal maxima estimated at approximately 25°C. Further similarity between the current study and Ehrlich et al. (1979) was noted for black croaker (*Cheilotrema saturnum*), with both studies suggesting a relatively high thermal tolerance.

Finally, the traumas induced during the heat treatment procedure impart substantial stress to the fish, which cannot be overcome for the most highly abundant species. Therefore, the results of the post-impingement return program at SGS, especially in comparison to the effective FRS at SONGS, suggests this was an ineffective method, providing little protection for common nearshore marine fishes of southern California. The current investigation indicates that the physical and physiological stresses must be limited, such as what is accomplished by the operation of the SONGS FRS, in order to measurably reduce the overall impingement mortality, as illustrated by the difference in the survival of entrapped anchovies during each study. Unfortunately, no known technologies exist that were able to meet these goals without endangering the station's ability to meet their power generation demands. As was noted previously, the SONGS FRS was designed into the original construction plans. Retrofitting the SGS forebay to include a similar FRS would require nearly insurmountable construction elements such as a dedicated return conduit, elevator, and guiding vanes, all of which work in concert to make the SONGS FRS effective.

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