Evaluation of Impingement and Entrainment Technologies for Harbor and Haynes Generating Stations

Final Report, July 2014

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ACRONYMS

AFB – aquatic filter barrier

CCRS – closed-cycle recirculating system

CWIS – cooling water intake structure

EPRI – Electric Power Research Institute

FPS – feet per second

GPM – gallons per minute

IMNODA – impingement mortality notice of data availability

LADWP – Los Angeles Department of Water and Power

MGD – million gallons per day

OTC – once-through cooling

Policy - California Statewide Water Quality Control Policy on “Use of Coastal and Estuarine Waters for Power Plant Cooling” (as amended on July 19, 2011)

VFD – variable frequency drives

EXECUTIVE SUMMARY

The Los Angeles Department of Water and Power is planning to eliminate the use of once through cooling at both Harbor and Haynes Generating Stations (Harbor and Haynes) by 2029. However, due to extended compliance schedules these facilities are subject to additional requirements. Specifically, the California Statewide Water Quality Control Policy on the "Use of Coastal and Estuarine Waters for Power Plant Cooling", as amended on July 19, 2011 (Policy), requires at Section (2)(C)(4)(b) that LADWP "*conduct a study or studies, singularly or jointly with other facilities, to evaluate new technologies or improve existing technologies to reduce impingement and entrainment.*". The requirement at Section (2)(C)(4)(b) is applicable to fossil facilities with compliance dates that extend past December 31, 2022 and Scattergood, Harbor, and Haynes have schedules extending beyond that date. LADWP has been funding jointly with other facilities, research to evaluate new fish protection technologies and to improve existing technologies.

The purpose of this document is to provide the results of LADWP's evaluation of alternative fish protection technologies for Harbor and Haynes as required at Section (2)(C)(4)(b) of the Policy. This evaluation was based on fish protection research conducted by the Electric Power Research Institute (EPRI) and others since 2002 and focuses on the site-specific biological and engineering considerations for these two facilities. This evaluation considered all currently available approaches and technologies to reduce both impingement and entrainment mortality, including new technologies and improvements to existing technologies. Results of the analysis are discussed separately for entrainment and impingement.

Harbor and Haynes Evaluation Results for Entrainment Mortality Reduction

The evaluation focused on five species of concern that made up over 95% of the entrainment at both facilities. The species of concern included blennies, croaker, gobies, northern anchovy and silversides (only entrained at Haynes). The results of a preliminary evaluation identified two technologies, fine-mesh modified traveling water screens and narrow-slot cylindrical wedgewire screens for further evaluation. Modified traveling water screens protect fish by collecting them on screens modified to enhance survival and transport them back to the source waterbody. Modified traveling water screens were selected since they were identified by the EPA as BTA for impingement in the proposed rule (April 20, 2011) and research has shown fine-mesh modified traveling water screens can provide relatively good performance depending on the species of concern and lifestage. Narrow-slot cylindrical wedgewire screens protect fish using a combination of low through slot velocity (velocity does not exceed 0.5 feet per second (fps) and placement in sufficient current to carry fish past the screens (ideally the ambient current exceeds the through slot current). Narrow-slot cylindrical wedgewire screens were evaluated due to their relatively good biological performance, depending on the lifestage and ambient source waterbody hydraulic conditions.

An engineering analysis determined that fine-mesh screens with a 0.5 mm mesh size could be installed at either facility. However, biological performance is estimated to be poor. Narrow-slot wedgewire screens were further evaluated for both facilities, the lack of adequate ambient current at Harbor would reduce biological efficacy, in addition is likely to cause debris and biofouling control issues that could incapacitate the screens and shut down Harbor's OTC unit. For Haynes, creating flow with additional pumping could provide the necessary sweeping current to control biofouling and debris; however the result would be to double fish entrainment into Haynes's intake channel and exposing additional organisms to the Haynes and Alamitos thermal discharge. A head capsule analysis was then performed to estimate the percentage of larvae that would be retained on the fine-mesh traveling water screens or excluded from entrainment by the narrow-slot wedgewire screens. Screen mesh sizes and slot widths of 0.5 mm, 0.75 mm, 1.0 mm and 2.0 mm were considered for each of the two technologies. Overall performance for each facility was calculated by multiplying the fraction excluded for each mesh size by the percent entrainment of all five species of concern. At Harbor, the overall retention/exclusion for the species of concern ranged from just under 30% at 0.5 mm to less than 1% for a 2 mm mesh/slot size. Most of the exclusion at 0.5 mm is from gobies (19.6%) and croakers (8.2%). At Haynes, overall retention/exclusion for the species of concern ranged from 43.5% for a 0.5 mm mesh/slot size to less than 1% for a 2 mm mesh/slot size. Silversides and gobies made up the bulk of the retention/exclusion at 23.6% and 13.0%, respectively. The head capsule analysis conducted was specifically designed to estimate retention of entrainable life stages for square mesh openings. Narrow-slot wedgewire screens have a single slot that extends over the entire length of the screen module and therefore depending on the angle of the larvae contacting the slot, it is possible that some larvae that would be excluded by a square mesh screen would be able to pass through the slot. The result is that this method may overestimate the levels of exclusion for cylindrical wedgewire screens. That said, the head capsule analysis does not take into account other mechanisms by which wedgewire screens reduce entrainment, such as hydraulic bypass (may provide little if any benefit for either Haynes or Harbor) or larval behavioral avoidance of the screens by larger larvae that have developed some swimming capability. Such factors are difficult to quantify.

For finemesh traveling water screens the overall biological performance results do not include consideration of the additional mortality due to issues at potential fish return locations. For Harbor the intake and proposed discharge location would be located near the terminus of Slip 5 where there is little ambient tidal flow and depending on the tidal stage the current can be dominated by Harbor's cooling water flow. This lack of ambient current near the end of Slip 5 hampers larval dispersion and could result in high levels of re-impingement on the fine-mesh screens. For Haynes two possible fish return locations were considered. The first is the San Gabriel River. However, the river receives the heated effluent from both the Haynes and Alamitos generating stations and the period of highest entrainment is during summer when the temperatures in the river are highest. During wet weather periods water quality can be poor due to the stormwater runoff into the river. The second fish return discharge location considered was return of the larvae back to the marina. However, flows in the marina are dominated by the cooling water withdrawals of Haynes and Alamitos such that there is a substantial risk of larval re-entrainment at one of these two facilities. In addition, the transport piping back to the Marina would be well over a mile in length.

The biological efficacy of narrow-slot wedgewire screens is complicated by the hydraulic conditions at both facilities. For narrow-slot wedgewire screens to be most effective a sweeping flow past the screens is necessary. This sweeping flow is needed to transport debris and non-motile organisms past the screens. At Harbor, where the intake is located at the end of Slip 5, tidal currents are expected to be an order of magnitude less than what is recommended to transport non-motile organisms and debris past the screens. Narrow-slot wedgewire screens at Haynes would be located within the intake channel. The flow in the canal is driven by the Haynes withdrawal. More pumping would be required to create an effective sweeping flow in the canal. This would nearly double the total withdrawal rate at Haynes and have the same shortcoming associated with transporting the fish and debris back to the source waterbody as the fish return needed with the finemesh modified traveling water screen alternative. The result could be a net increase, rather than decrease in overall entrainment mortality.

A flow reduction of 50% has been achieved at Haynes, 45% of which took place after the July 2011 interim Policy condition went into effect and the current schedule to replace Units 1 and 2 with dry cooling is scheduled to be completed prior to the requirement for interim impingement. The associated 77% entrainment reduction should minimize entrainment on an interim basis. Further, LADWP has a target date of 2022 for conversion of Units 1 and 2 to closed-cycle cooling and will be fully compensating for losses through mitigation as required at Section 2.C.3 of the Policy.

Harbor and Haynes Evaluation Results for Impingement Mortality Reduction

New two year impingement studies are underway at both Harbor and Haynes. Results from the first year of the study indicate a significant reduction in impingement at both facilities compared to the study completed in 2006. The recent study resulted in annual impingement estimates of 5,375 and 20,036 finfish for Harbor and Haynes, respectively, which represented reductions of 69.5 and 73.8%, respectively, when compared to 2006. Neither of these facilities uses heat treatment, eliminating that source of impingement mortality. Based on the results of the evaluation of options to reduce both impingement and entrainment LADWP plans to conduct a similar evaluation of technologies that only reduce impingement mortality.

Conclusion

Due to site-specific issue and the entrained species of concern, neither modified fine-mesh traveling water screens nor narrow-slot cylindrical wedgewire screens are practical interim technologies to reduce impingement and entrainment. Modified traveling water screens while feasible from an engineering standpoint they are not practical from a biological performance standpoint with an estimated overall performance of less than 2.25% that does not include consideration of additional mortality associated with the lack of suitable return locations at either facility. Cylindrical wedgewire screens are not expected to be feasible due to competing uses for navigation and boat dockage in Slip 5 for Harbor and lack of ambient water current to carry away debris removed from the narrow-slot screens. From a biological standpoint estimated exclusion is less than 30% and due to lack of ambient water current impingement of larval fish onto the screens could result in additional mortality. For Haynes, cylindrical wedgewire screens could be deployed in the intake channel, to accomplish this would require additional pumping to control biofouling and carry entrainable life stages past the screens. However, the volume of pumping necessary would double Pacific Ocean water flow into the intake channel that could potentially result in a net increase in overall entrainment mortality due to return of organisms to the San Gabriel River and exposure to Alamitos and Haynes thermal discharge.

Since the amended Policy has gone into effect, LADWP has reduced Haynes cooling water flow by 45% resulting in an equivalent reduction in entrainment and LADWP is targeting a further flow reduction to achieve 77% by the end of 2023. Further, LADWP plans to fully compensate for the remaining entrainment losses through mitigation as required by Section 2.C.3 of the Policy. The benefits of mitigation are likely to provide greater benefits to California fisheries than either of the technologies evaluated.

New two year impingement studies are underway at both Harbor and Haynes. Results from the first year of the study indicate a significant reduction in impingement at both facilities compared to the prior 2006 study. Neither of these facilities uses heat treatment in a manner that results in fish mortality, eliminating that source of impingement mortality. As discussed LADWP plans to proceed with an evaluation of technologies that only reduce impingement mortality.

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INTRODUCTION

The California Statewide Water Quality Control Policy (Policy) on the "Use of Coastal and Estuarine Waters for Power Plant Cooling", as amended (July 19, 2011), requires at Section (2)(C)(4)(b) that LADWP:

"*Conduct a study or studies, singularly or jointly with other facilities, to evaluate new technologies or improve existing technologies to reduce impingement and entrainment.*"

The requirement at Section (2)(C)(4)(b) is only applicable to fossil facilities with compliance dates that extend past December 31, 2022. The requirement applies to all three LADWP's once-through cooling (OTC) facilities that include Harbor, Haynes and Scattergood. However, since compliance applies on a unit by unit basis, LADWP compliance must be implemented in a carefully planned sequence. LADWP is targeting compliance for Scattergood Generating Station before the end of 2022 and therefore the requirement will not applicable to that facility. However, since both the Harbor and Haynes Generating Stations have compliance dates that extend beyond 2022, this requirement is applicable to those facilities.

The Electric Power Research Institute (EPRI) was requested by the Los Angeles Department of Water and Power (LADWP) to assist the Department in satisfying this requirement. LADWP has in fact been funding jointly with other utilities and/or companies, research to evaluate new fish protection technologies and to improve existing technologies. This EPRI research program funds research on fish protection topics that include Sections 316(a) and (b) of the Clean Water Act and hydro issues. Prior to that LADWP was a funder of the research in 2002, 2003, 2006, 2007, 2009, 2010, 2012 and 2013. The purpose of this document is to summarize the results of the EPRI research funded jointly by LADWP and others relative to fish protection technologies and providing a detailed discussion of the potential application of that research to Harbor and Haynes to inform the decision on interim fish protection measures.

The organization of this report is as follows:
In the remainder of Chapter 1

- Provide a general overview of the major categories of fish protection technologies;
- Summarize research to evaluate new technologies or to improve existing technologies; and
- Conduct a high level evaluation of potential use of fish protection technology categories for potential further evaluation for Harbor and Haynes.

Chapter 2 – Provide an engineering evaluation of feasibility of fine-mesh screens and exclusion devices.

Chapter 3 – Provide a description of the methods used to evaluate potential performance of fine-mesh screens.
Chapter 4 – Provide the results of the fine-mesh screen performance evaluation.
Chapter 5 – Provide a discussion of the results.
Chapter 6 – Summary and conclusions.

1.1 Overview of Impingement and Entrainment Reduction Technologies

Over the last decade EPRI has been conducting research on fish protection technologies for cooling water intake structures (CWIS) on behalf of the electric power generation industry in anticipation of new federal regulations implementing §316(b) of the Clean Water Act. During this period, EPRI has interacted on a regular basis with fish protection technology vendors, conducted field and laboratory studies on alternative fish protection technologies, and conducted workshops and conferences on this subject.

There are basically five options for fish protection for CWISs that include:

1. Flow Reduction;
2. Exclusion Devices;
3. Collect and Transfer Technologies;
4. Behavioral Devices; and
5. Change in Intake Location.

Following is a brief discussion of each of these options:

1.1.1 Flow Reduction

Examples of flow reduction technologies range from use of wet or dry closed-cycle re-circulating systems (CCRSs) to reduced use of existing condenser cooling water pumps, use of variable frequency drives (VFDs) on those pumps to achieve a finer level of adjustment of flow and use of recycled water (ex., use of grey water from a wastewater treatment facility). A reduction in the amount of cooling water entering a CWIS directly reduces the number of entrainable life stages that pass through the facility. This is also true for impingeable life stages. In addition, reducing cooling water flow also reduces the water velocity passing through the screens, providing an added benefit.

In the proposed Federal 316(b) Rule and Impingement Mortality Reduction Notice of Data Availability (IMNODA) the EPA stated they were considering allowing facilities to assume that a reduction in cooling water flow would result in a proportional reduction in impingement and entrainment. The Policy has identified CCRSs as BTA and LADWP has committed to their use for all existing once-through cooled (OTC) units on a phased schedule. In terms of the non-CCRS options, there are no new emerging developments for flow reduction. In terms of the other options such as reduced cooling water pump use, VFDs, and use of alternative sources of cooling water, these options have been available for decades. The Contra Costa and Pittsburg Generating Stations both installed VFDs decades ago to reduce impingement losses of striped bass stocked for recreational fishing. The Palo Verde Nuclear Generating Station in Arizona is an example of a large facility that uses municipal wastewater for cooling make-up water. A major disadvantage of reducing cooling water flow is the direct impact on power generation output. Less cooling water reduces the generating unit's efficiency and power output. Therefore, use of VFDs or reduced cooling water pump use is not possible, if the majority of entrainment coincides with periods of maximum power demand such as the hottest times of the year. An additional consideration for flow reduction, for a given level of power generation as flow is reduced the same amount of heat is rejected in the condenser to the smaller volume of cooling water. This results in a smaller but hotter thermal discharge to the receiving waterbody that could potentially adversely affect species that are less thermally tolerant.

1.1.2 Exclusion Devices

Examples of exclusion devices include cylindrical wedgewire screens, aquatic filter barriers (AFB) and porous dykes. Other than use of CCRS, these devices tend to be the best performing fish protection technologies. As the name suggests, this class of technologies function by excluding impingeable and entrainable life stages from entering the CWIS. Cylindrical wedgewire screens are constructed by wrapping a wedge shaped wire around a support frame resulting in a smooth surface with no mesh. Instead there is a continuous slot from one end of the cylinder to the other. Exclusion is accomplished by use of a combination of a small screen slot size (i.e., 0.5 mm or larger) and a low through screen velocity (generally 0.5 fps or less). The screen slot size needed to maximize effectiveness depends on the size of the entrainable life stages that enter the CWIS hydraulic zone of influence and potentially subjecting them to impingement and entrainment. Generally, the practical lower screen mesh size limit for exclusion is 0.5 mm. In terms of the ability of fish to avoid the CWIS, for impingeable life stages (i.e., those fish that would pass through a 3/8 inch mesh screen), the EPA determined in the now remanded 316(b) Phase II and proposed new rule, that a through screen velocity not to exceed 0.5 fps is protective and can be used for compliance. The EPA determination of this criterion is supported by EPRI research (EPRI Technical Report 1000731). The results of a literature review of fish swimming speeds at various velocities are shown in Figure 1. Of the 536 values gathered during the literature survey, only one value for a small fish was below the criterion.

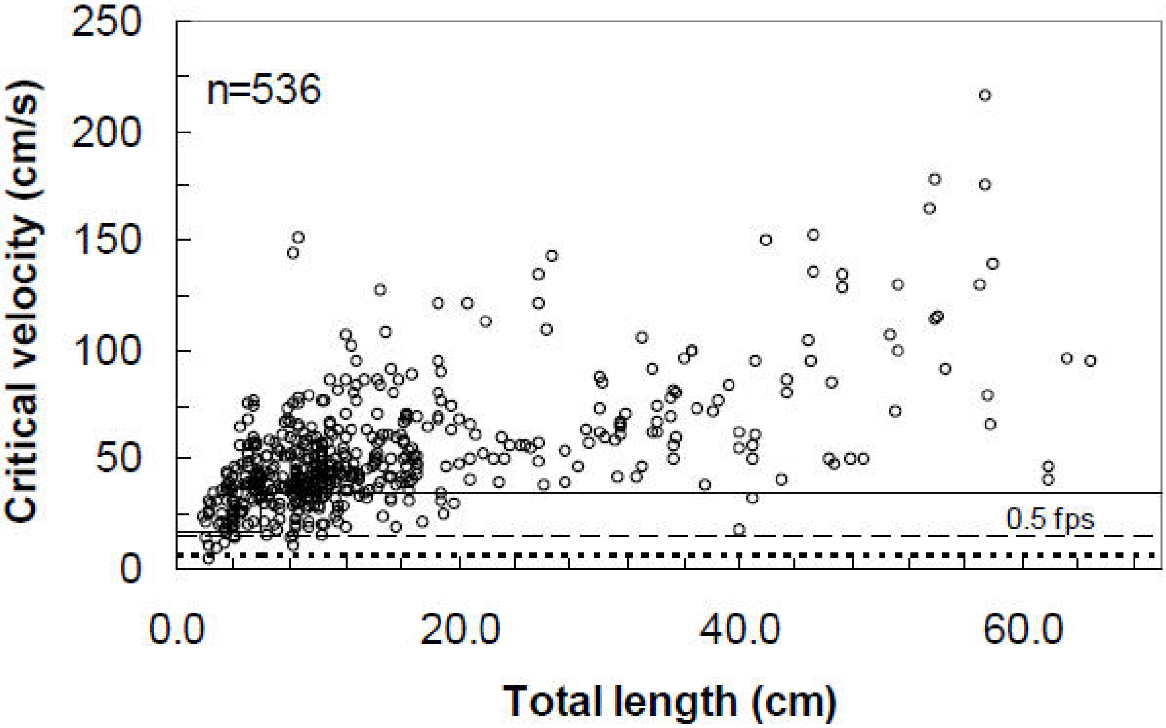

Figure 1-1 - Relationship of fish size (cm) and swimming velocity (cm/s) based on 536 values collected from a literature survey by EPRI (Technical Report 1000731). The dashed line is equivalent to an approach velocity of 0.5 fps. The dotted line is equivalent to the Rule's 0.5 fps maximum through screen design velocity. The solid line represents a threshold proposed by the National Marine Fisheries Service.

While very early life stages of fish (i.e., fish eggs and early stage larvae) tend to behave as passive water particles, entrainable life stages can also benefit from exclusion depending on the screening slot width, ambient sweeping current velocity and larval stage, such that biological performance can exceed performance based on exclusion alone. Having an ambient current sweeping velocity past the screens can aid in carrying entrainable life stages past the screens and increase performance beyond that predicted by exclusion due to the slot size alone. Additionally, as larvae reach a sufficient age/size to develop musculature, their behavior can also aid in screen entrainment avoidance.

The newest exclusion devices proposed are use of Filtrix Candles (Figure 1-2). Filtrix Candles make use of small disks to filter water and requires a relatively large source waterbody footprint. This technology has never been deployed at an electric power generating station and is considered experimental in nature. The most widely deployed exclusion devices for reducing impingement and entrainment are wide (9.5 mm) or narrow-slot (<9.5 mm) wedgewire screens. There have been improvements in the design of cylindrical wedgewire screens, most notable in methods to control debris accumulation and biofouling. Further, a cylindrical wedgewire screens have been successfully deployed and operated in the San Francisco Bay area, with adequate ambient sweeping currents, at the Conoco-Phillips Refinery in Rodeo and the San Francisco

Exploratorium. The EPA, in the proposed §316(b) Rule preamble said that these devices were not designated as BTA, since they cannot be used at all facilities. The problem is that these devices must extend into the source waterbody where navigation issues, water depth (i.e. shallow water) and hydraulic forces can make them impractical for use at some facilities.

Figure 1-2 – Photograph of a Filtrix Candle module

1.1.3 Collect and Transfer Technologies

Examples of these technologies include modified-Ristroph, Geiger, Hydrolox and Beaudrey and other Water Intake Protection (WIP) traveling water screens. These screens work by using technologies that minimize the damage to fish ("fish friendly") that are collected from the intake screens and returned back to the source waterbody to a location that will maximize survival and minimize risk of reimpingement or entrainment in the thermal discharge. Generally, these screens are rotated continuously to minimize the time between finfish collection and return to the source waterbody. The systems typically utilize a low pressure screen spraywash to remove fish prior to high pressure debris removal. A fine-mesh screen (i.e., as small as 0.5 mm) can be used for collection of entrainable life stages. A positive aspect of these technologies is that it is relatively easy to install them as a replacement for existing screens. For that reason, the EPA designated these screens combined with a fish return as BTA in the proposed 316(b) Rule. Performance of these screens is highly variable depending upon the site-specific species and lifestages subject to impingement and entrainment at any given facility. There have been a number of new screens developed for use in the U.S. over the last decade. Most of the new screens have advantages in terms of preventing by-pass of debris and organisms and overall debris control improvements. EPRI has been conducting laboratory and/or field research on these technologies and results have shown there is little benefit to very early larval stages that have not yet developed scales and musculature. At some facilities the lack of a suitable fish return location in reasonably proximity which avoids the risks of return to the CWIS or the thermal discharge can also be an issue.

1.1.4 Behavioral Devices

Examples of these technologies include use of lights, sound (both high and low frequency), bubble curtains, electric fields and diversion devices such as louvers. This category of technology works by either acting as "scarecrows" (ex., use of light and sound) to induce fish to move away from the CWIS, or using hydraulic forces to guide fish away from the intake (ex: diversion systems). Such devices can be deployed independently or used in combination with other fish protection or exclusion technologies. An advantage of these devices is their relatively low cost and the fact that they can generally be used at almost any CWIS. A major disadvantage of these technologies is that they are only applicable for impingeable sized organisms with little, if any, benefit to entrainable life stages. A further disadvantage is that many impingeable sized species do not respond to these devices. For example only species with air bladders (e.g., herring species) tend to respond to sound. It has also been found that in other cases, while there may be an initial response, fish acclimate and no longer respond once they get used to the stimuli.

1.1.5 Change in Intake Location

While not a technology per se, for some waterbodies, locating the intake in an area with lower densities of fish can reduce impingement and entrainment. This approach has successfully been used in the Great Lakes where there are significantly fewer fish offshore than near shore. It has also been considered for use in the Lower Mississippi River where significantly fewer fish are found in the deeper portions of the river than near the surface. On the west coast, relocating the intake was also considered for the San Onofre Nuclear Generating Station (SONGS). However, it was determined that changing the intake location within practical limits would simple change the species composition of impinged and entrained organisms without a significant overall reduction.

1.2 Summary of EPRI Fish Protection Technology Research

Following is a summary of research studies funded by LADWP jointly with other facilities to evaluate new fish protection technologies and/or improve existing technologies:

1. Evaluation of Angled Bar Racks and Louvers for Guiding Fish at Water Intakes, EPRI Technical Report 1005193, EPRI 2001
2. Evaluation the Effects of Power Plants on Aquatic Communities: Summary of Impingement Survival Studies, (EPRI Technical Report 1007821, EPRI 2003Laboratory Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intake Structures, EPRI Technical Report 1005339, EPRI 2003
3. Laboratory Evaluations of an Aquatic Filter Barrier for Protecting Early Life Stages of Fish, EPRI Technical Report 1005534, EPRI 2004
4. Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of fish at Cooling Water Intakes, EPRI Technical Report 1010112, EPRI 2005
5. Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intake Structures: Chesapeake Bay Studies, EPRI Technical Report 1012542, EPRI 2006.

6. Technical Resource Document for Modified Ristroph Traveling Screens: Model Design and Construction Technology and Technology Installation and Operation Plans, EPRI Technical Report 1013308, November 2006
7. Design Considerations and Specifications for Fish Barrier Net Deployment at Cooling Water Intake Structures, EPRI Technical Report 1013309, EPRI October 2006
8. Laboratory Evaluation of Modified Ristroph Traveling Screens for Protecting Fish at Cooling Water Intakes, EPRI Technical Report 1013238, June 2006
9. Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intake Structures: Chesapeake Bay Studies, EPRI Technical Report 1012542, EPRI 2006.
10. Fine-mesh Traveling and Vacuum Screens, Approach Velocity, Impingement Survival and Spraywash Pressure: Supplemental Laboratory Studies, EPRI Technical Report 1023769, EPRI 2009.
11. Laboratory Evaluation of 2.0 mm Fine-mesh Traveling Water Screens for Fish Protection of Larval Fish: Exclusion and Survival Studies: EPRI Technical Report 1020663, EPRI 2009.
12. Latent Impingement Mortality Assessment of the Geiger Multi-disc$^{\text{TM}}$ Screening System at the Potomac River Generating Station, EPRI Technical Report 1013065, July 2007 Numeric and Physical Model Study of Fish Barrier Net Designs for $^{\text{Com}}$plex Hydraulic Environments, EPRI Technical Report 1016808, November 2008
13. Beaudrey Water Intake Protection (WIP) Screen Pilot-Scale Impingement Survival Scale Study, EPRI Technical Report 1018490, March
14. Evaluation of Continuous Screen Rotation and Fish Survival: Studies at Plant Barry, Mobile River, AL. EPRI Technical Report 1016807, January 2010
15. Laboratory Evaluation of Fine-mesh Traveling Water Screens. EPRI Technical Report 1019027, December 2010.
16. Evaluation of Factors Affecting Juvenile and Larval Fish Survival in Fish Return Systems at Cooling Water Intakes. EPRI Technical Report 1021372, December 2010
17. Laboratory Evaluation of the Beaudrey Water Intake Protection Screen for Protecting Early Life Stages of Fish at Cooling Water Intake Structures. EPRI Technical Report 1019864, May 2011.

In addition to the specific technology related research summarized above, EPRI developed and periodically updates a fish protection technology manual that discusses all known fish protection technologies and operational measures. Following is a summary of the manual's history:

1. Research Update on Fish Protection Technologies for Water Intakes, EPRI Technical Report 104122, 1994
2. Fish Protection at Cooling Water Intakes: Status Report, EPRI Technical Report 114013, December 1999.
3. Fish Protection at Cooling Water Intake Structures: A Technical Reference Manual. EPRI Technical Report 1014934, December 2007

EPRI is in the process of making another major update to be issued after the EPA issues the Final 316(b) Rule. Additionally EPRI, in conjunction with the American Fisheries Society 2011 Annual Meeting, conducted a symposium on 316(b) that included papers on a variety of 316(b) related topics and included a number of papers on fish protection technologies.

1.3 Identification of Potential Fish Protection Technologies for Further Evaluation for Haynes and Harbor

It was determined that three of the fish protection approaches did not warrant further evaluation and the reason for dropping each from further consideration is discussed below:

1.3.1 Change in Intake Location

Relocating the intake for the Harbor Generating Station is not practical from an engineering standpoint. As shown in Figure 1-3, the Harbor CWIS is located deep in Los Angeles Harbor near the end of Slip 5. Densities of entrainable and impingeable fish are likely to be relative evenly distributed within the harbor. The nearest location where there would likely be significantly lower densities of aquatic organisms would be in deep ocean water miles offshore. Any attempt to relocate the intake by running a pipe through the Los Angeles Harbor to such a location would be impractical due to costs and disruption to ship navigation in the Harbor.

Relocating the intake for the Haynes Generating Station is also infeasible for similar reasons. The Haynes generating units are located almost 2 miles inland from the coast. As shown in Figure 4, the entrance to the intake channel is located in the Long Beach Marina Cooling water withdrawn at that point travels under the San Gabriel River and then down the intake channel shown in Figure 4. The only option to relocate the intake where there might be significantly lower densities of impingeable and entrainable life stages is miles offshore resulting in the same issues as Harbor, disruption of local marina water navigation and an impractical cost given the facilities plans to eliminate all once-through cooling by 2029.

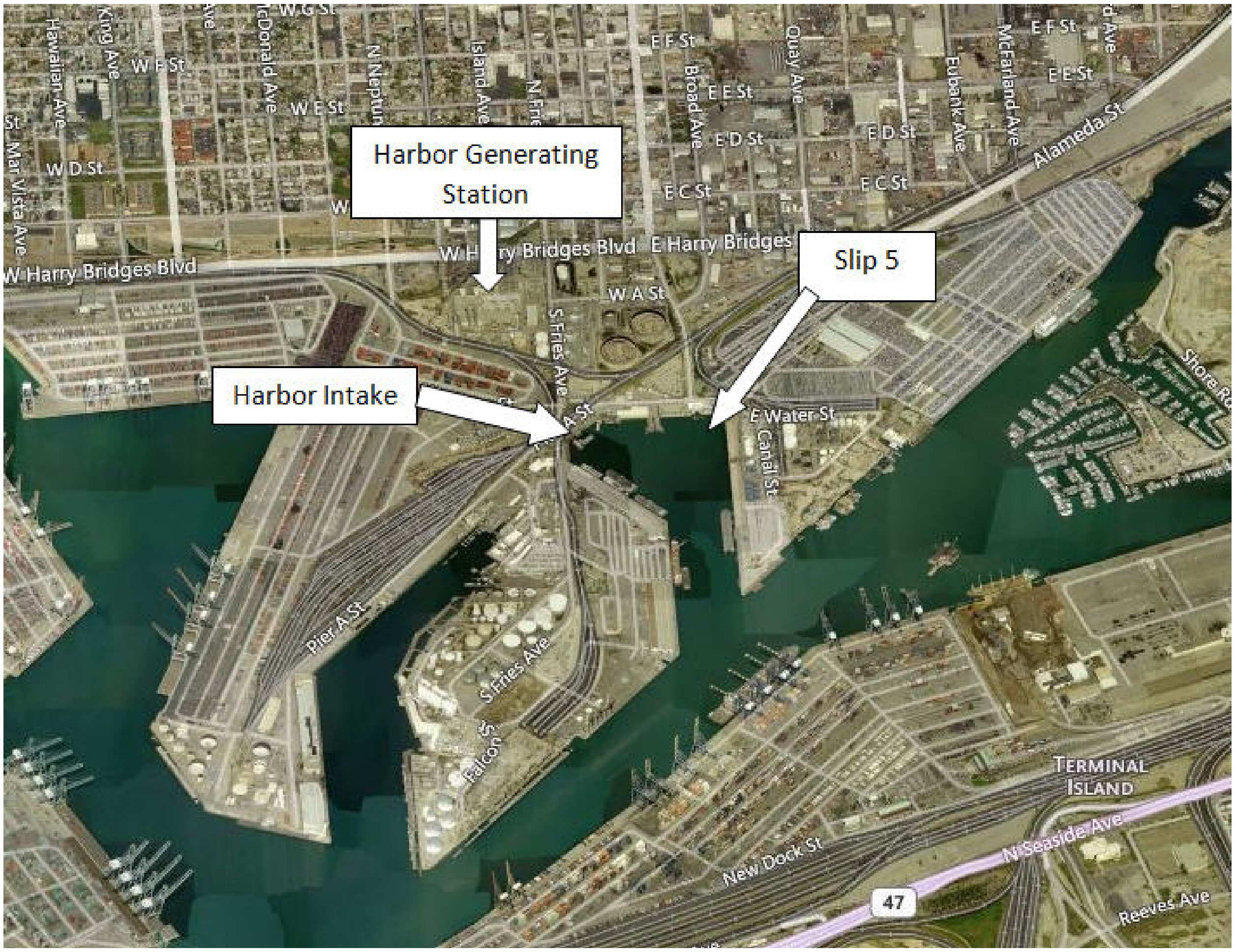

Figure 1-3 – Location of Harbor Generating Station cooling water intake structure

Figure 1-4 – Location of the Haynes Generating Station intake channel and entrance to the cooling water intake structure.

1.3.2 Behavioral Devices

The Cooling Water Policy requirement at Section (2)(C)(4)(b) requires facilities subject to the requirement to evaluate new technologies or improvements to existing technologies that reduce impingement and entrainment. Behavioral devices, while potentially effective for some impingeable species are not effective for entrainable life stages. Eggs and early life stages of finfish tend to behave as passive water particles. It is only the larger entrainable finfish that have developed scales, musculature, and reached a size where they have the ability to alter their location in ocean and estuarine environments. EPRI is not aware of any research that indicates larger entrainables detect and exhibit an avoidance response to lights, sound, bubble curtains or similar devices.

1.3.3 Flow Reduction

For both Harbor and Haynes LADWP has already committed to eliminating use of once-through cooling water through a combination of Unit retirements, repowering and use of dry cooling rather than wet cooling. LADWP considered use of wastewater for condenser cooling at Scattergood. The option was considered feasible for this facility due to the close proximity to the Hyperion Waste Water Treatment Facility. However, neither Harbor nor Haynes are near wastewater treatment plants that can provide adequate cooling water on a sufficiently reliable basis to meet the cooling water needs for these facilities, making this option impractical for these facilities. In terms of the other flow reduction options (i.e., reduced cooling water pump use and VFDs), since the California once-through cooling water has gone into effect, Haynes has already achieved a significant flow reduction of 552.9 MGD that includes conversion of Units 5 and 6 to dry cooling. Haynes total cooling water flow in 1990 was 1,014 MGD (704,000 gpm). In 2002 the replacement of once through cooled Units 3 and 4 to closed-cycle cooled Unit 8 achieved a 46 MGD (32,000 gpm) reduction (4.5%). More recently, after the California Once-through Cooling Policy went into effect, an additional interim flow reduction of 506.9 MGD (320,000 gpm) or an additional flow reduction of 45% for an overall 50% reduction since 1990. Further, the current target date for converting Haynes Units 1 and 2 to dry cooling is 2022 that will bring the total flow reduction to 77% and will exclude Units 1 and 2 from being subject to Section (2)(C)(4)(b). In terms of further flow reductions for either Harbor or Haynes, the benefit of such reductions, to the extent possible, depend on the ability of those facilities to reduce flow during periods of high entrainment.

Due to LADWP efforts to integrate more renewable energy into the Los Angeles area electric system and current plans to convert to dry cooling, there is a need for flexibility to dispatch these units on a diel and seasonal basis, such that a commitment to fixed reductions at specific times of the day or seasons of peak entrainable life stage abundance is not possible. For the purposes of power system and grid reliability, the Harbor and Haynes units must remain fully functional with full generation capability throughout the year. During the high periods of potential entrainment (i.e. summer months) are when then units are most critical to the power system. Therefore this approach will not be given further consideration.

Two fish protection approaches, use of exclusion devices and fine-mesh traveling water screens did warrant further consideration and the basis for that determination is discussed below:

1.3.4 Exclusion Devices

Two of the examples mentioned, aquatic filter barriers and porous dykes are not considered practical for use at Haynes and Harbor. There has only been a single full scale AFB deployment and that was at the Lovett Generating Station on the Hudson River. While this technology demonstrated relatively high performance, it requires a large surface area to create the low velocity needed to prevent impingement and retention of entrainable life stages on the net. Further successful operation requires some sweeping flow so that aquatic organisms and debris blown off the nets by the air burst system are carried away from net. In the absence of a sweeping velocity entrainable organisms will simply flow back onto the net. Deployment of this technology at Harbor and Haynes would be particularly problematic. Harbor is located at the end of Slip 5 with little sweeping current in the slip itself. In addition, waters in the Slip 5 are used for navigation and deployment of an AFB would infringe on other water uses such as navigation. The presence of a marina in front of the Haynes intake channel precludes deployment at that facility. Deployment inside the intake channel is not practical since the only flow in the canal is the cooling water flow. The result is that after an air burst to remove debris and entrainable life stages the material would flow back onto the AFP immediately after the airburst. The most recent porous dyke deployment is at the Port Washington Generating Station on Lake Michigan. While the porous dyke was shown to be effective it has the same issues for Harbor and Haynes as the AFB. There is lack of space for such a structure at either facility. Further such structures have not been used for fish protection in marine environments. When fouling and debris collect there is no way to remove it and therefore the system must be by-passed to remain in operation. A final concern for this technology is that for many species the rocks or boulders used to form the dyke can serve as spawning substrate for some species that may increase entrainment of some species. The third option is cylindrical wedgewire screens. While this is a technology that has also been available for decades, advances in designs have been made. Most notable are alternative designs for deployment and debris control. There is now a functioning mechanically cleaned system deployed in San Francisco Bay demonstrating these devices are capable of operating in Pacific Coast marine biofouling environments. However that deployment is located in a hydraulic environment with adequate ambient water current to carry away the debris and biofouling organisms once removed.

1.3.5 Collect and Transfer Technologies

As discussed in Section 1.1.3 this technology can be installed at almost any facility and depending on the species and lifestages of finfish present and site-specific conditions that include the nature of the source waterbody and facility layout and intake location these technologies can potentially achieve relatively good performance especially if entrainment is dominated by non-fragile later stage larvae. However, for very early stage larvae, collection on the screens can result in greater mortality than entrainment through the cooling system at some facilities. This is especially true for facilities with relatively short transit times through the cooling system and/or during periods of lower ambient water temperature. Additionally, effective biological performance requires a suitable fish return location that avoids fish being drawn back to the intake or exposure to the thermal discharge. Also as noted in Section 1.1.3 there have been significant improvements made in designs to improve debris handling and fish protection.

The above discussion provides the basis for further evaluation of fine-mesh screens and narrow-slot wedgewire screens for Harbor and Haynes. The primary focus of the evaluation is engineering issues and the potential biological performance for entrainable life stages. The implication of these technologies for impingement will be covered in the discussion in Chapter 5.

2 ENGINEERING EVALUATION OF MODIFIED FINE-MESH AND CYLINDRICAL WEDGEWIRE SCREENS

This Chapter considers the issues, including cost and technical (i.e., engineering) feasibility, associated with deploying fine-mesh traveling water screens and cylindrical wedgewire screens at Harbor and Haynes.

2.1 Fine-mesh Traveling Water Screens with a Fish Return

Course-mesh traveling water screens modified with fish protection features were determined by the EPA to be BTA for impingement, in part since they can be deployed at almost any intake. This is also generally true for fine-mesh screens at most facilities. Evaluating the practicality of a modified traveling water screen design retrofit includes consideration of both the screens and the fish return. Each of these components is critical for biologically effective modified traveling water screens installation. If one part of the system is not practical from either an engineering or biological performance perspective then the entire project is no longer practical. This section evaluates the practicality of both the screens and fish return at Harbor and Haynes.

2.1.1 Screen Types

There are a number of different modified traveling water screen designs that incorporate fish friendly features that are available for use at CWISs including the Ristroph-style screen most commonly installed at CWISs (EPRI 2006), Bilfinger MultiDisc Screen (EPRI 2007, 2009a); Beaudrey “W” Intake Protection (WIP) screen (EPRI 2009b), and the Hydrolox polymer, belt-screen (ASA 2008). Most of these screens can be installed in existing CWISs with standard traveling water screens without impacting station operations or major structural changes. For both Harbor and Haynes the existing screens could be replaced with through-flow modified traveling water screens. However, it is important to consider a number of factors to assess the practicality of installing such screens that are discussed in the sections that follow.

2.1.1.1 Civil Structures:

The screen houses for Harbor and Unit 8 at Haynes already incorporate standard through-flow traveling water screens. It is believed that retrofitting these CWISs with through-flow modified TWS can be completed without substantial structural modification. If that is the case, the installation would require approximately the same level of effort as required to remove and replace standard screens for maintenance or rebuild. However, if other screen types are considered (e.g., dual-flow, Hydrolox, MiltiDisc, WIP) care needs to be taken to ensure that the existing screen guides are compatible with the new screen and the screen opening can accommodate the new screen.

Stationary screens are currently installed in the Units 1 & 2 screen houses at Haynes. The addition of modified TWS may require some structural modifications to accept the new screens. Regardless of the CWIS, the existing screen guides and supports should be evaluated to determine their condition and if they are compatible with the new screens. The existing electrical service at both Harbor and Haynes Unit 8 should be sufficient to handle the electrical needs of a modified traveling water screen retrofit. The existing electrical service at Haynes Units 1 & 2 CWISs would need to be evaluated to verify that it will meet the power requirements for the screen motors, screen wash pumps and control system. If insufficient power is available then additional capacity would be needed. Power to a screen house with modified traveling water screens should be able to provide a 480 volt, 3 Phase, 60 Hertz current.

Depending on existing screen wash pressures and flows, new high- and low-pressure screen wash pumps and supplemental fish return pumps may be required. Additional efforts would include connection of the new spray wash system and modifications or installation of the fish return system. New screen controls may be needed as part of the modified traveling water screen retrofit. The new controls should be connected to the overall station control system allowing the condition of the screens to be monitored and controlled remotely. Any new control system should be designed to allow the screen rotation speed to adjust automatically based on debris loading. The control panels would be housed in a weather-tight structure to prevent damage from the elements.

2.1.1.2 Hydraulics:

Depending on the mesh size and screen type, retrofitting either Harbor or Haynes with modified traveling water screens could have a direct effect on intake hydraulics (e.g., head loss, vortices), circulating water pump performance (i.e., pump submergence), and screen hydraulics (skewed flows, head loss). The estimated head loss across a through-flow modified TWS with different meshes is provided on Table 2 for Harbor and Table 1-2 and Table 2-2 for Haynes Units 1&2 and Unit 8, respectively.

Careful selection of the screen mesh could allow modified traveling water screens with meshes as small as 1.0 mm to be used without a dramatic increase in head loss, assuming the screens can be kept clean. The head losses associated with specific screen open areas, as shown on Table 2 through Table 2-2, are for through-flow screens, where the flow has to pass through the mesh twice. Alternative screen designs, (e.g., Dual-flow, MiltiDisc, WIP), only require the flow to pass through the mesh once, potentially reducing head loss depending on the open area of the screen frames and baskets . Using one of the alternative screen designs may allow LADWP to use meshes down to 0.5 mm at both facilities without a substantial increase in head loss.

2.1.1.3 Debris Handling:

The fish-friendly features of modified traveling water screens improve the debris handling capabilities of the screens when compared to standard traveling water screens. Fish holding buckets hold fish and other debris as they are lifted out of the water preventing them from falling back into the screen bay and re-impinging. The low-pressure spray wash acts as a pre-wash removing fish and loose debris which avoids exposure of fish to the high-pressure spray wash designed for debris removal. Fine-mesh increases the retention of smaller debris, reduces the amount of debris entanglement on the screen mesh and provides a smooth surface for debris to slide across and into the return trough. However, these features also result in an increased co-mingling of fish/debris discharged to the source waterbody. Continuous rotation of the screens reduces the debris accumulation period, reducing the total amount of debris on the screen, and ultimately head loss. During periods of high debris loading, the screen rotation speed can be increased, further reducing the debris accumulation period.

The added debris handing and screening efficiency afforded by modified traveling water screens should reduce the debris-related operational issues at both Harbor and Haynes.

2.1.2 Fish and Debris Return:

A properly designed fish/debris return is needed to safely return organisms removed from the modified traveling water screens back to the source waterbody. Fish return designs are very site-specific. Factors such as, distance to the source water body, height from the intake top deck to the water surface, local topography, macro-fouling potential and the number and size of TWS all impact the design. An additional factor that can impact survival of organisms returned to the source waterbody is availability of a suitable location that avoids the risk of re-impingement or thermal plume entrainment (exposing finfish to the thermal discharge if their thermal tolerance is exceeded. Both Harbor and Haynes have site constraints that complicate the design and practicality of fish returns.

The proposed design for the Harbor fish return uses a single, combined fish and debris return that would be located inside the east intake pipe, exit through the east wall of the intake structure, and discharge in Slip 5 approximately 120 ft. northeast of the CWIS (Figure 2-1). A second, redundant fish return was included in the design to address anticipated biofouling. Depending on the tidal stage, the flow within Slip 5 can be dominated by the Harbor withdrawal. This poses a substantial risk of re-circulating collected organisms back to the intake. Mixing with the thermal plume is not an issue at Harbor because the thermal discharge, discharges into Slip 1.The fish return for Haynes Units 1, 2 and 8 includes a common return pipe that runs along the intake channel and discharges back to Alamitos Bay (Figure 2-2). A second, redundant fish return pipe was also included in the design to address biofouling. Selecting the fish return location for Haynes is highly problematic due to issues for each of the potential locations considered. The closest location would be into the San Gabriel River. However, the San Gabriel River receives the once-through cooling discharges for both Haynes and the Alamitos Generating Station. There is little ambient water flow in the river except during storm events and those events contribute significant non-point source storm water runoff which in turn adversely affects water quality. Return of collected organisms would expose them to additional mortality from heat and/or poor water quality. For these reasons a fish return location in Alamitos Harbor was selected for the fish return. While water quality conditions at this location are adequate this location poses also poses a significant risk of additional mortality for two reasons. First, the dominant flow in Alamitos Harbor is generated by cooling water flow from both the Haynes and Alamitos Generating Stations resulting in a substantial significant risk that entrainable life stages that survive collection and transport to the return location will be re-entrained into the intakes of one of these facilities resulting in additional mortality. Second the study of the transport distance to the return location is approximately 1.5 miles long. A study of egg and larval fish and shellfish survival in a fish return this distance has never been conducted. While EPRI has conducted a study for fish returns in freshwater, that study did not address the issue of biofouling and predation of early life stages by marine plankton and large predators may also be collected on fine-mesh screens.

2.1.2.1 Design and Size:

The length of the fish returns, existing infrastructure and other site constraints, limits the ability to use open channel fish returns at both sites. Alden addressed this by designing both fish returns as pressurized, closed conduit systems. Pressure in the returns would be provided by fish-friendly pumps (screw-centrifugal pumps). The velocity within the fish returns was selected to prevent organisms from holding within the fish return system. The return pipes and pumps were sized for the combined flow from both the fish and debris washes to take advantage of the increased flow. However, if the fish and debris wash water is not combined, smaller fish return pipes and smaller pumps could be used and the existing debris return/disposal system used to handle the debris wash.

The fish returns would be installed in a manner to minimize any trenching or disturbance to adjacent property. At Harbor the new fish returns could be anchored to the inside of the east intake pipe. The fish returns at Haynes would parallel the intake channel and pass under the Pacific Coast Highway and San Gabriel River within one of the intake pipes. Routing the return pipes through the intake pipes will reduce the effective cross sectional area of that intake pipes. This is not expected to adversely affect the cooling water supply because the diameter of the fish returns would be substantially smaller than the diameter of the intake pipes

2.1.2.2 Biofouling:

Biofouling of the fish return lines is expected to be an issue at both facilities. The current designs incorporate a redundant line to allow one pipe to be dewatered for cleaning while the second line is put in service. This also provides redundancy if repairs need to be made to one line.

2.1.2.3 Discharge:

The discharge location at each site was selected to take advantage of existing infrastructure while minimizing the contact with the thermal plume and reducing potential re-circulation into the intake. However, hydraulic modeling of the intake or a field study looking at potential re-circulation would be needed to optimize the discharge locations.

2.1.3 Conclusions:

After reviewing available information from both Harbor and Haynes, it was determined that modified TWS could be installed from an engineering standpoint. However, the layout of each site complicates the design of the fish returns and precludes the use of open channel, gravity-driven systems. Pressurized fish return systems combined with fish-friendly pumps remains practical from an engineering standpoint. However, the designs for both Harbor and Haynes pose a significant risk of additional mortality due to re-circulation back to the intake with associated re-impingement regardless of fish collection and transport survival.

2.2 Cylindrical Wedgewire Screens

Narrow-slot cylindrical wedgewire screens are designed to protect aquatic organisms through a combination of low through-slot velocity (<0.5 ft/sec) and exclusion. For wedgewire screens to function efficiently a sweeping current is needed to transport fish and debris past the screens. In absence of a sweeping current there is nothing to prevent non-motile organism (i.e., fish eggs and early stage larvae and debris) from re-impinging on the screen face. This will reduce both the biological efficacy for entrainable life stages and increase potential plugging of the screens. Biofouling is a concern with narrow-slot cylindrical wedgewire screens, especially in high fouling marine environments. Also mechanical brush cleaning systems have proven effective in San Francisco Bay for a relative small scale deployment and the presence of adequate sweeping velocity. Screen materials such as copper-nickel alloy have been shown to significantly reduce biofouling of wedgewire screens. However, due to the strict water quality limits for copper, this material cannot be used for either Harbor or Haynes.

2.2.1 Harbor

The proposed design for Harbor includes three rows of cylindrical wedgewire screens on a bulkhead wall in front of the existing CWIS. The bulkhead would extend out about 30 ft from the front of the existing CWIS. A boat exclusion zone would then extend an additional 15 ft beyond the bulkhead wall. To generate sufficient surface area to maintain a 0.5 fps maximum intake velocity would require 14 – 6 foot diameter screens. The screens could be mounted on a bulkhead in two rows, one above the other as shown in Figure 2-3.

The Harbor CWIS is located along the northwest corner of Slip 5 within the Inner Los Angeles Harbor. At this location tidal fluctuations and the intake withdrawal are the primary source of currents. The magnitude of these currents within Slip 5 are not known; but, a recent sediment transport study (Tetra Tech 2010) indicated that within the east basin channel the tidal currents are weak, on the order of 2 cm/sec (0.07 ft/sec) or less for all tidal constituents. These tidal currents are an order-of-magnitude less than the 1.0 ft/sec bypass velocity recommended to transport fish and debris from the screens. Without sufficient bypass flow non-motile organisms and debris could re-impinge on the screens. The lack of sufficient sweeping flow would also reduce the effectiveness of automatic, screen cleaning system.

Slip 5 is used as a ship dock, which prevents screen deployment in this location. LADWP does not own the property immediately in front of the intake that would be needed to install the screens. Currently, the school of oceanography uses this slip to dock its boats at and adjacent to LADWP’s intake, in addition there are other boats that dock at Berths 181 – 183 which are just adjacent to Harbor’s intake and would make it highly problematic to obtain the necessary permissions and permits to relocate the intake and install wedgewire screens.

2.2.2 Haynes

Narrow-slot cylindrical wedgewire screens were evaluated at Haynes and potentially could be installed in the intake channel. However, an artificial sweeping current would be needed to remove impinged fish and debris from the screens. The only method available to create this current is to install, fish-friendly bypass pumps within the intake channel downstream of the cylindrical wedgewire screens.

A bypass velocity of about 1.0 feet/sec at the last screen is recommended to transport fish and debris from the screens. Therefore, a bypass flow of approximately 700 cfs would be needed to create this sweeping velocity within the intake channel. This would nearly double the total Haynes withdrawal, increasing it from 784 cfs to 1,484 cfs although the additional flow would not enter the generating station or be used for cooling purposes. Units 5 & 6 have recently been retired which would allow their CWISs to be modified with suitable pumps to create the sweeping flow past the Units 1, 2 and 8 CWISs. After passing through the bypass pumps, fish and debris would be conveyed through a large diameter discharge pipe to either the San Gabriel River or directly back to the ocean. A return pipe to the San Gabriel River would be about 1,000 feet long. Discharging to the San Gabriel River may result in the increased mortality due to increased thermal stress on organisms, because the river is used as the discharge canal by both Haynes and Alamitos. Discharging to the ocean would require a 2 to 3 mile long tunnel running under several roads and residential areas. Studies conducted in California have shown that predation losses to entrainable life stages that colonize such tunnels can be significant. The result is that even if such a system were installed there would likely be significant additional mortality to the excluded organisms during the transport back to the Pacific Ocean. A second, redundant fish return tunnel can be constructed to address anticipated biofouling, by allowing one tunnel to be taken off-line and cleaned while the other is in use Routing the discharge pipe back to Alamitos Bay was not considered because a discharge of this magnitude could impact recreation within the bay and lead to recirculation of non-motile organisms.

Narrow-slot cylindrical wedgewire screens located in the intake channel could be added to the circulating water system at Haynes. For these screens to be effective an artificial bypass flow would be needed. The result would nearly double the intake flow, potentially doubling the number of organisms susceptible to entrainment. Discharging organisms to the San Gabriel River may negate any potential environmental benefit for the same reasons discussed for the fine-mesh traveling water screen return location (i.e., exposure to the thermal discharge from Haynes and Alamitos and poor water quality). The construction and operation of a bypass system of this scale also presents many engineering challenges. Even if the organisms can be returned back to the ocean, mortality from predation of entrainable life stages by biofouling organisms in the return tunnels may negate any environmental benefits. Because of these shortcomings narrow-slot cylindrical wedgewire screens are not considered practical for application at this time.

Table 2-1 Estimated Through-screen velocity and head loss with various meshes at Harbor (assumes clean screens)

Clear Square Opening (mm)	Standard Wire Sizes	Wire Diameter (inches)	% Open Area (OA) Mesh	% OA Back-up Mesh	% OA Composite (Mesh)	% OA Framing[1]	% OA Composite (Mesh +Frame)	Through-screen Velocity (ft/sec)[2,3]	Head Loss (inches) (Clean Screen)[2,3]
9.5	12 Ga	0.105	61%	100%	61%	86%	52%	0.8	0.7
9.5	14 Ga	0.080	68%	100%	68%	86%	58%	0.7	0.5
4.0	16 Ga	0.063	51%	100%	51%	86%	44%	1.0	1.0
4.0	18 Ga	0.047	59%	100%	59%	86%	51%	0.8	0.7
2.0	18 Ga	0.047	39%	100%	39%	86%	34%	1.2	1.6
2.0	.23 mm with backup[4]	0.009	81%	86%	69%	86%	59%	0.7	0.5
1.0	.23 mm with backup[4]	0.009	66%	86%	57%	86%	49%	0.9	0.8
0.5	.23 mm with backup[4]	0.009	47%	86%	40%	86%	35%	1.2	1.5

1. Open area based on typical modified traveling water screens.
2. Mean Lower Low Water (El. -0.0 ft) used for velocity and head loss calculations
3. Assumes 2 circulating water pumps and 4 screens in service
4. Back-up mesh assumed to be 14 gage wire with 1-inch square openings

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Table 1-2 - Estimated through-screen velocity and head loss with various meshes at Units 1 & 2 Haynes (assumes clean screens)

Clear Square Opening (mm)	Standard Wire Sizes	Wire Diameter (inches)	% Open Area (OA) Mesh	% OA Back-up Mesh	% OA Composite (Mesh)	% OA Framing[1]	% OA Composite (Mesh +Frame)	Through-screen Velocity (ft/sec)[2]	Head Loss (inches) (Clean Screen)[2]
9.5	12 Ga	0.105	61%	100%	61%	86%	52%	1.7	2.8
9.5	14 Ga	0.080	68%	100%	68%	86%	58%	1.5	2.3
4.0	16 Ga	0.063	51%	100%	51%	86%	44%	2.0	4.1
4.0	18 Ga	0.047	59%	100%	59%	86%	51%	1.7	3.0
2.0	18 Ga	0.047	39%	100%	39%	86%	34%	2.6	6.9
2.0	.23 mm with backup[3]	0.009	81%	86%	69%	86%	59%	1.5	2.2
1.0	.23 mm with backup[3]	0.009	66%	86%	57%	86%	49%	1.8	3.3
0.5	.23 mm with backup[3]	0.009	47%	86%	40%	86%	35%	2.5	6.5

1. Open area based on typical modified traveling water screens.
2. Mean Lower Low Water (El. -2.7 ft) used for velocity and head loss calculations
3. Back-up mesh assumed to be 14 gage wire with 1-inch square openings.

Table 2-2 - Estimated through-screen velocity and head loss with various meshes at Unit 8 Haynes (assumes clean screens)

Clear Square Opening (mm)	Standard Wire Sizes	Wire Diameter (inches)	% Open Area (OA) Mesh	% OA Back-up Mesh	% OA Composite (Mesh)	% OA Framing[1]	% OA Composite (Mesh +Frame)	Through-screen Velocity (ft/sec)[2]	Head Loss (inches) (Clean Screen)[2]
9.5	12 Ga	0.105	61%	100%	61%	86%	52%	1.2	1.4
9.5	14 Ga	0.080	68%	100%	68%	86%	58%	1.1	1.1
4.0	16 Ga	0.063	51%	100%	51%	86%	44%	1.4	2.0
4.0	18 Ga	0.047	59%	100%	59%	86%	51%	1.2	1.5
2.0	18 Ga	0.047	39%	100%	39%	86%	34%	1.8	3.4
2.0	.23 mm with backup[3]	0.009	81%	86%	69%	86%	59%	1.0	1.1
1.0	.23 mm with backup[3]	0.009	66%	86%	57%	86%	49%	1.3	1.6
0.5	.23 mm with backup[3]	0.009	47%	86%	40%	86%	35%	1.8	3.2

1. Open area based on typical modified traveling water screens.
2. Mean Lower Low Water (El. -2.7 ft) used for velocity and head loss calculations
3. Back-up mesh assumed to be 14 gage wire with 1-inch square openings

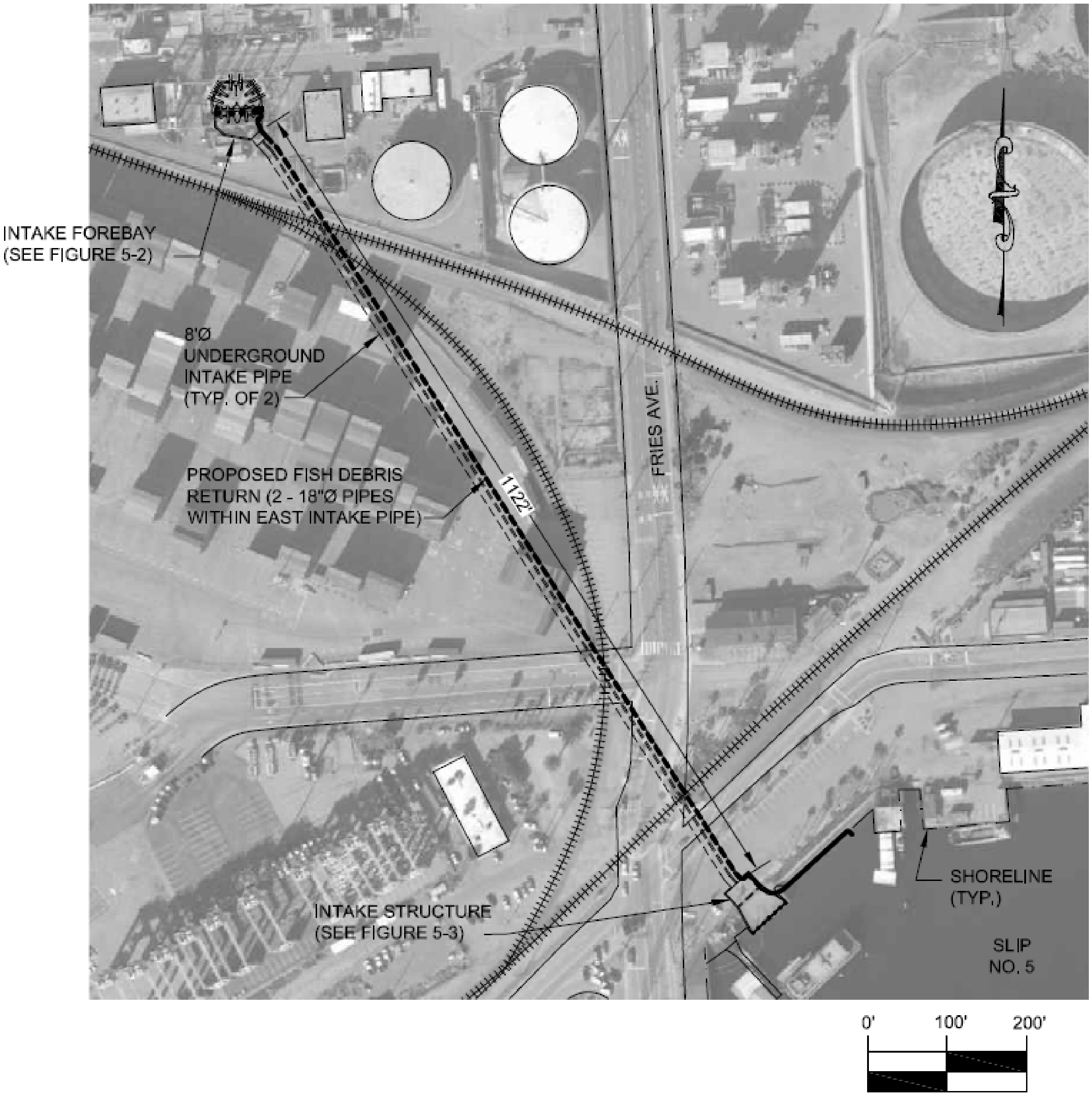

Figure 2-1 - Proposed fine-mesh traveling screen alternative at Harbor Generating Station

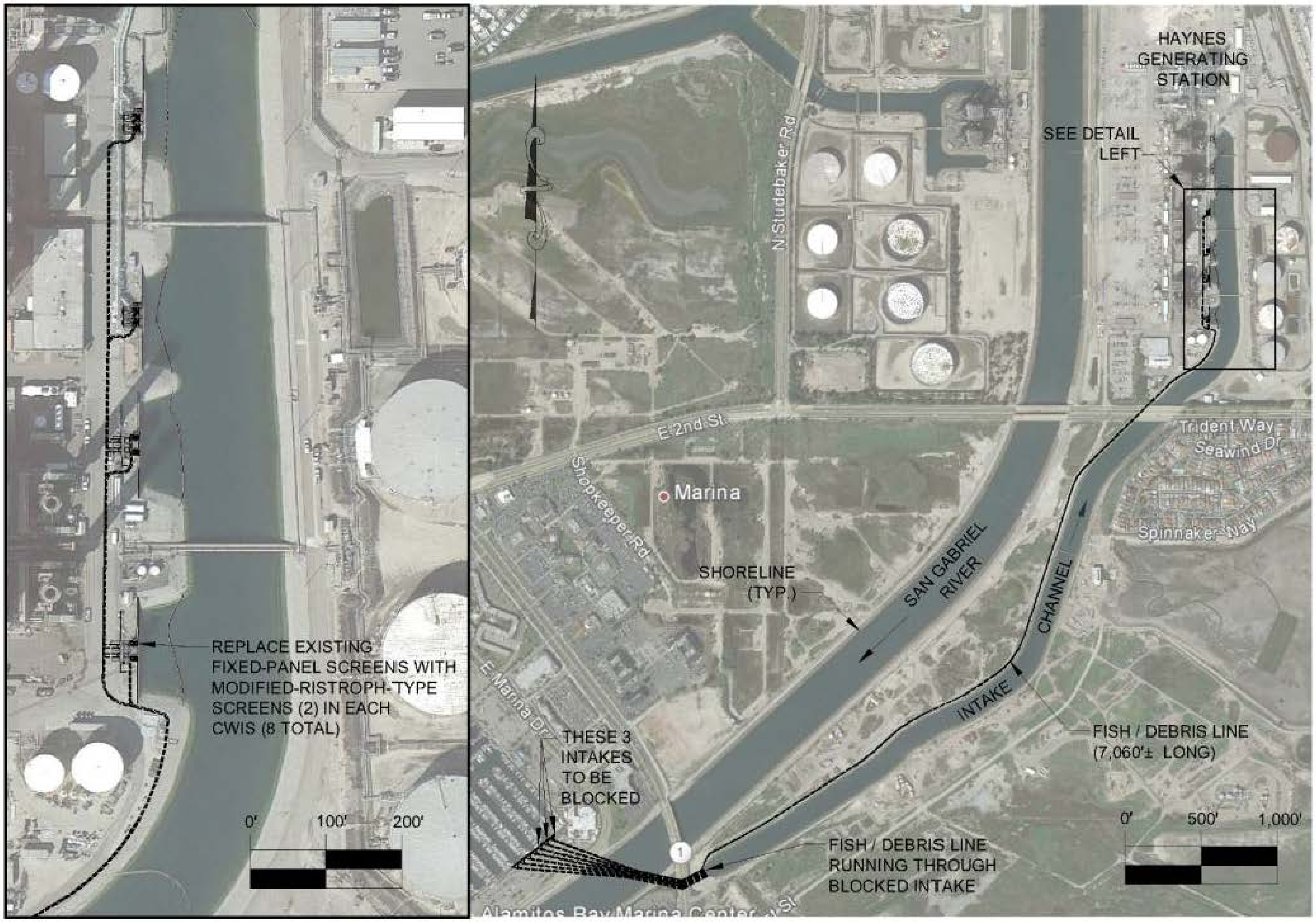

Figure 2-2 – Conceptual design for new modified-Ristroph screens in the existing screen houses

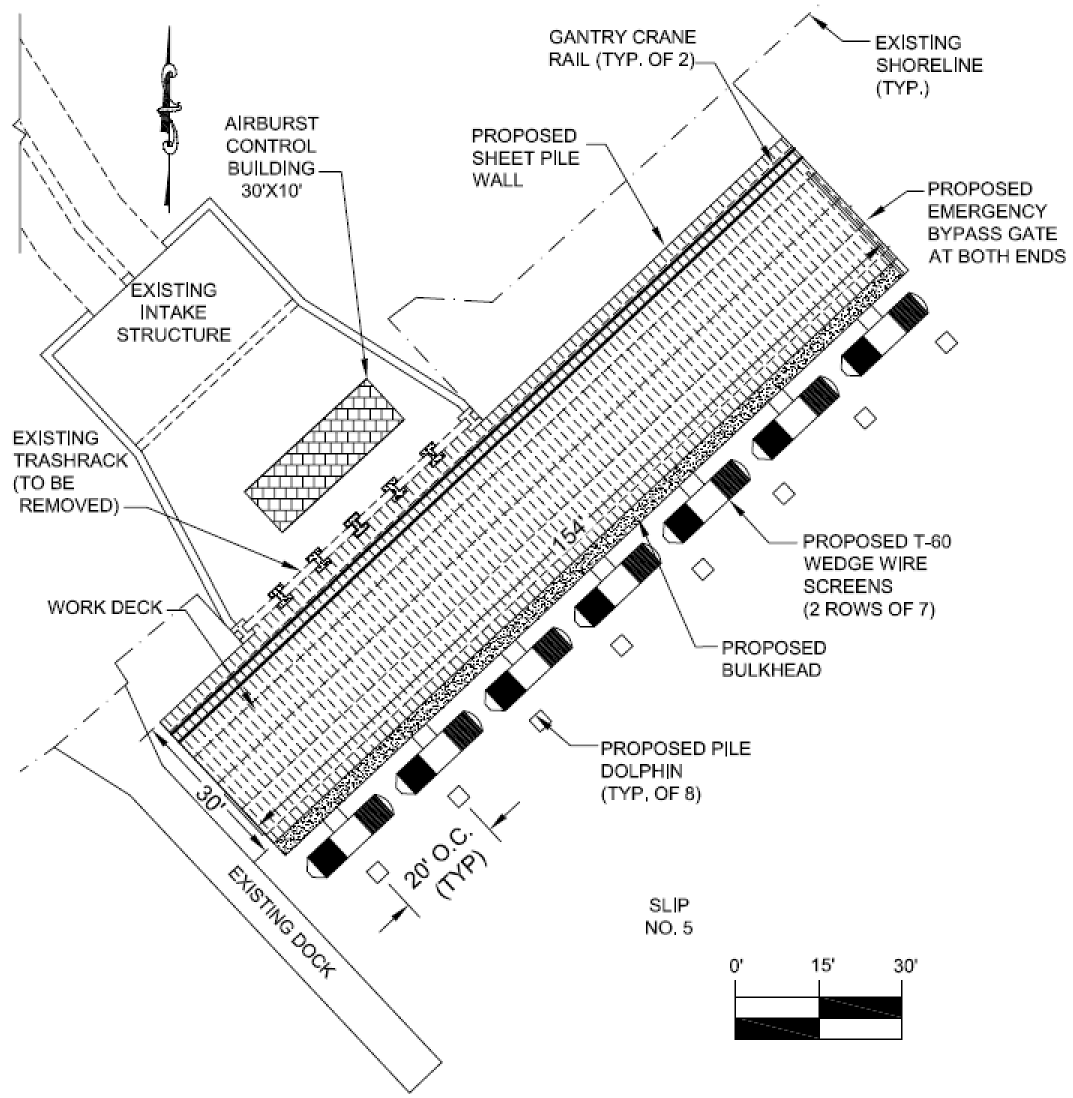

Figure 2-3 – Conceptual design for new narrow slot cylindrical wedgewire screens at Harbor Generating Station

3
METHODS

As discussed in Chapter 1, EPRI has been engaged in conducting field and laboratory studies on course and fine-mesh traveling water screens and wide- and narrow-slot wedgewire screens for over a decade. EPRI has also collected and summarized all available performance studies for fine-mesh traveling water screens. This information is used in addition to head capsule analysis and the analytical methods discussed below to inform protection biological performance for the two technologies. This chapter focuses on the methodology used to evaluation the potential biological performance of fine-mesh and cylindrical wedgewire screens for entrainable life stages for Harbor and Haynes. The methodology builds on the existing entrainment studies for both facilities to identify potential species of concern. Head capsule width is then used to estimate the species of concern that would be collected on the fine-mesh screens or excluded by cylindrical wedgewire screens versus the number that would still be entrained by those technologies. For fine-mesh screens survival off the screens is estimated.

3.1 Species of Concern

This section presents information on the entrainment sampling completed at the Harbor and Haynes from January through December 2006. Entrainment sampling occurred every two weeks resulting in a total of 26 surveys at both plants. The results from the two studies presented in Chapter 4 are used to identify the species of concern that will be used to evaluate the potential effectiveness of various screen mesh sizes at reducing the entrainment of these species. The species of concern were selected largely on their abundance in the entrainment studies, but are also representative of the various habitats in the intake source waters.

Fish eggs were also collected, enumerated, and identified to the lowest taxonomic level possible, but they are not considered in this evaluation of screen performance for several reasons. First, many of the fishes that were collected in highest abundance during the studies do not have planktonic eggs that could be entrained. Gobies, blennies, and silversides all lay eggs in nests that are located in burrows in the mud (gobies), or attached to rocks (blennies) or vegetation (silversides). More importantly, unlike fish larvae which do have non-compressible body parts that prevent them from passing through small mesh screen opening, fish eggs are compressible and very small and would still be entrained through all but the smallest mesh sizes (Table 3-1). While fish eggs are not considered in this assessment of screen performance, the methodology for assessing the benefits of different screen sizes could be adjusted to accommodate the continued entrainment of eggs for fishes, such as croakers and anchovies, which have planktonic eggs.

3.1.1 Harbor Generating Station Entrainment Studies

Entrainment samples at the Harbor were collected by towing a bongo-style frame with two plankton nets through the water column at a station located just offshore from the intake structure (Figure 3-1). The samples were collected by towing the net obliquely through the water column from the surface down to approximately 13 cm (6 in.) off the bottom, and back to the surface. Two replicate tows were conducted at the intake with a target sample volume of 15–20 m3 (4,000–5,300 gal) of filtered water for each net on the bongo frame. The net was redeployed if the target volume was not reached during the initial tow. Sampling was conducted four times per 24-hour period—approximately once every six hours.

The wheeled bongo frame used for sampling consisted of 60 cm (2 ft) diameter net rings with plankton nets constructed of 333 µm (0.013 in.) Nitex® nylon mesh. Each net was fitted with a Dacron sleeve and a plastic cod-end container to retain the organisms. Each net was equipped with a calibrated General Oceanics 2030R flowmeter, allowing the calculation of the amount of water filtered. Coordinates of each sampling station were determined using a differential global positioning system. At the end of each tow, the nets were retrieved and the contents of the nets were gently rinsed into the cod-end with seawater. Contents were washed down from the outside of the net to avoid the introduction of plankton from the wash-down water. Samples were carefully transferred to pre-labeled jars with preprinted internal labels and preserved in a 4–10% buffered formalin-seawater solution. The samples were taken to the laboratory where the target organisms were removed, identified, and enumerated.

Table 3-1 - Reported diameters (mm) of fish eggs collected during entrainment studies in southern California. Information from Moser (1996).

Family	Taxa	Common Name	Egg Diameter Range (mm)
Clupeidae	*Sardinops sagax*	Pacific sardine	1.3 - 2.1
Engraulidae	Engraulidae unid.	anchovies	0.7 - 0.8 x 1.2 - 1.5
Serrandidae	*Paralabrax* spp.	sand and kelp basses	0.8 - 1.0
Haemulidae	*Xenistius californiensis*	salema	0.7 - 1.0
Sciaenidae	Sciaenidae unid.	croakers	0.7 - 1.3
Sciaenidae	*Atractoscion nobilis*	white seabass	1.2 - 1.3
Sciaenidae	*Cheilotrema saturnum*	black croaker	0.8 - 0.9
Sciaenidae	*Genyonemus lineatus*	white croaker	0.8 - 0.9
Sciaenidae	*Roncador steanrnsi*	spotfin croaker	0.7 - 0.8
Sciaenidae	*Seriphus politus*	queenfish	0.7 - 0.8
Sciaenidae	*Umbrina roncador*	yellowfin croaker	0.7 - 0.8
Kyphosidae	*Girella nigricans*	opaleye	1.0 - 1.1
Labridae	*Oxyjulis californica*	senorita	0.7 - 0.8
Labridae	*Semichossyphus pulcher*	Californa sheephead	0.8
Sphyraenidae	*Sphyraena argenteus*	Pacific barracuda	1.0 - 1.4
Scombrdae	*Scomber japonicus*	Pacific mackerel	0.8 - 1.3
Pleuronectiformes	Pleuronectiformes unid.	flatfishes	0.6 - 3.1
Paralichthyidae	Paralichthyidae unid.	sand flounders	0.6 - 0.9; 1.2 - 1.4
Paralichthyidae	*Citharichthys* spp.	sanddabs	0.6 - 0.8
Paralichthyidae	*Paralichthys californicus*	California halibut	0.7 - 0.8
Pleuronectidae	*Microstomus pacificus*	Dover sole	2.1 - 2.7
Pleuronectidae	*Parophrys vetulus*	English sole	0.8 - 1.1
Pleuronectidae	*Pleuronichthys* spp.	turbots	0.8 - 2.1
Pleuronectidae	*Pleuronichthys guttulatus*	diamond turbot	0.8 - 0.9

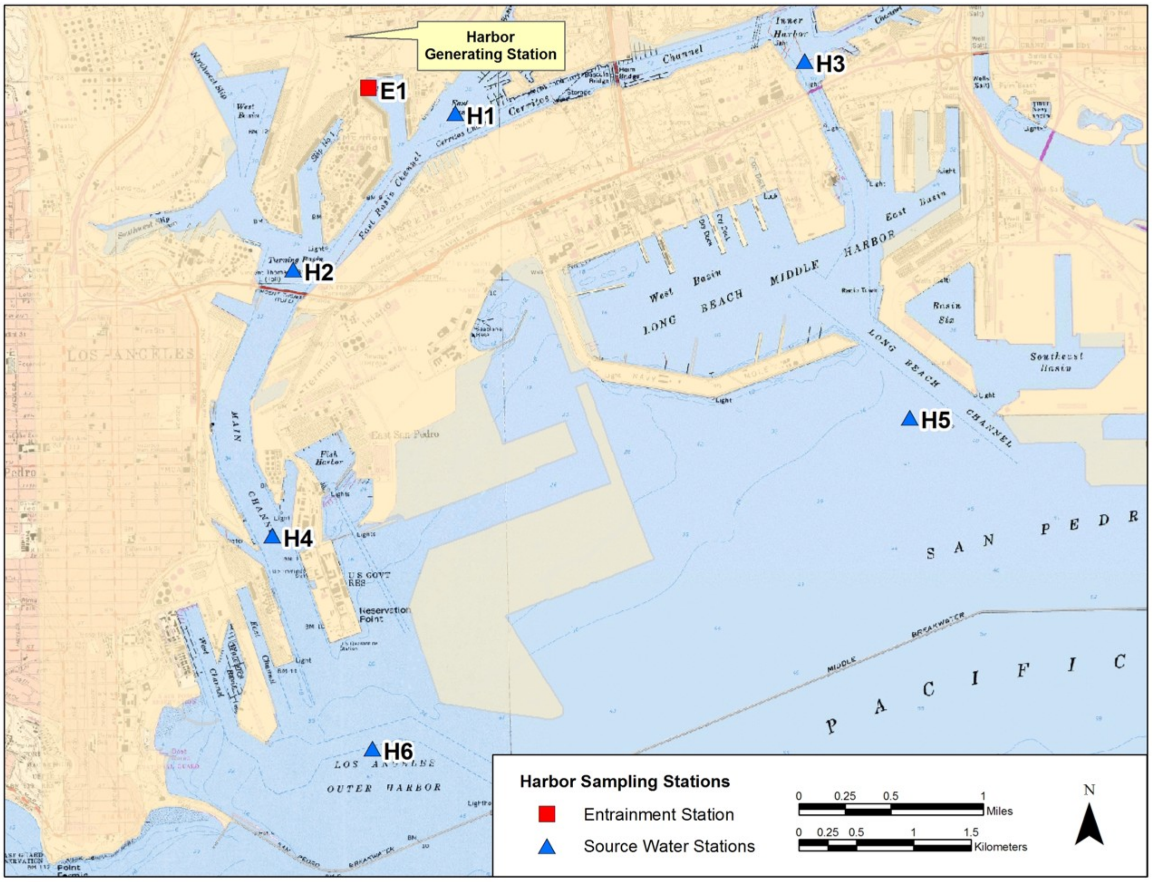

Figure 3-1 - Map showing locations of the Harbor Generating Station entrainment and source water sampling stations.

3.1.2 Haynes Generating Station Entrainment Studies

Composition and abundance of ichthyoplankton larvae entrained by Haynes were determined by sampling in the immediate proximity of the cooling water intake at two stations along the bulkhead at the entrance to the intake channel inside Alamitos Bay (Figure 3-2). In order to determine the appropriate sampling methodology, data from a previous 316(b) demonstration were assessed. During the previous 316(b) demonstration, horizontal inflow at the intake structure was measured at all intake depths (-0.6 to –2.9 m [-2 ft to –9.5 ft]); velocities were determined to be highest just above bottom (IRC 1981). Therefore, entrainment samples were collected using an oblique tow through the entire water column. At each intake station, a 0.5 m- (1.6 ft-) diameter 333 µm- (0.013 in.-) mesh plankton net was towed by hand from the docks (parallel to the bulkhead) approximately 3 m (10 ft) upcurrent from the intake. The net was towed until a volume of 15–20 m^3 (4,000–5,300 gal) was filtered. The net was equipped with a calibrated General Oceanics 2030R flowmeter, allowing the calculation of the amount of water filtered. At the end of each tow, the contents of the net were gently rinsed into the cod-end with seawater, in the same manner as described above for the Harbor samples. Sampling was conducted four times per 24-hr period--once every six hours. The samples were taken to the laboratory where the target organisms were removed, identified, and enumerated.

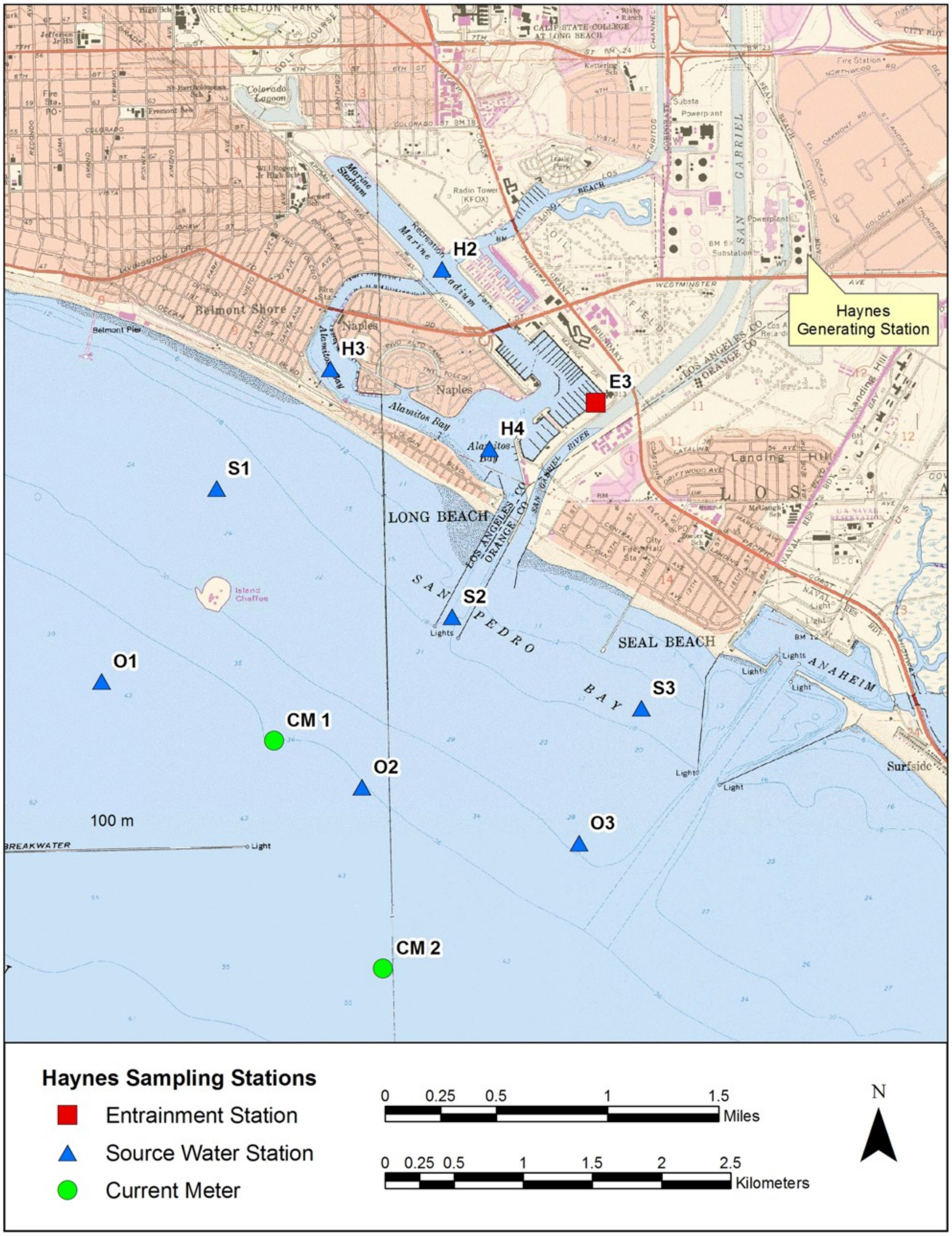

Figure 3-2 - Map showing locations of the Haynes Generating Station entrainment (E3) and source water sampling stations.

3.2 Head Capsule Analysis

Recent studies on larval fish entrainment at most of California's coastally-sited power plants have resulted in an extensive database on larval fish composition, seasonal abundance, and size frequencies. By re-measuring a subset of the most abundant larval fishes collected during these studies, we can establish species-specific dimensions for those larvae that are known to occur in the source waters adjacent to facilities utilizing OTC. By establishing a mathematical relationship between overall length of the larvae and the parameters of head capsule width and depth, potential screening designs can take into consideration the types of larvae likely to be at risk of entrainment at the Harbor and Haynes. The data reported here were first presented in a study conducted by Tenera (2011).

The data used in Tenera (2011) were collected using 335 µm (0.013 in.) Nitex mesh nets towed in the immediate vicinity of CWIS intakes at eight power plants in central and southern California, including both Harbor and Haynes (Table 3-2). Samples collected from all the studies were initially preserved in 5% buffered formalin seawater solution and transferred to 70 to 80% ethanol after approximately 72 hours and prior to removing the target organisms. Samples were examined under a dissecting microscope and all fish larvae were removed and identified to the lowest possible taxonomic level.

The study (Tenera 2011) included analysis of 15 taxa of fishes (Table 3-3). The larvae measured were randomly selected from a subset of the entrainment samples collected from the studies at the eight facilities. Some of the taxa included measurements from multiple species which share similar larval morphology and cannot be reliably identified to species. The body length (standard [notochord] length [NL]), head width, and head depth (Figure 3-3) were measured for each specimen to the nearest 0.1 mm (0.004 in.) using a digital camera mounted on a dissecting microscope interfaced with ImagePro® digital imaging analysis software. The system was recalibrated whenever necessary to adjust the microscope magnification to accommodate larvae of different sizes.

Table 3-2 - Location and collection period of larval fish samples.

Power Plant	Owner (present)	Intake Latitude	Intake Longitude	Sample Period
Moss Landing	Dynegy Inc.	36° 48.292' N	121° 47.130' W	1999–2000
Diablo Canyon	Pacific Gas and Electric Company	35° 12.456' N	120° 51.407' W	1996–1999
Scattergood	LADWP	33° 54.985' N	118° 26.106' W	2006–2007
El Segundo	NRG Energy, Inc.	33° 54.433' N	118° 26.031' W	2006–2007
Redondo	AES Southland, LLC	33° 50.409' N	118° 23.718' W	2006–2007
Haynes	LADWP	33° 45.121' N	118° 06.556' W	2006–2007
Harbor	LADWP	33° 45.932' N	118° 15.790' W	2006–2007
South Bay	Dynegy Inc.	32° 36.869' N	117° 05.942' W	2001–2003

Table 3-3 - List of larval fish taxa measured for head capsule dimensions and notochord lengths.

Common name	Taxon (included species)
anchovies	*Engraulis mordax*
blennies	*Hypsoblennius* spp.
cabezon	*Scorpaenichthys marmoratus*
clingfishes	*Gobiesox* spp.
croakers	*Genyonemus lineatus, Seriphus politus*
flatfishes	*Citharichthys stigmaeus, Paralichthys californicus*
gobies	*Acanthogobius flavimanus,* CIQ goby complex, *Rhinogobiops nicholsii*
kelpfishes	*Gibbonsia* spp*.*
monkeyface prickleback	*Cebidichthys violaceus*
Pacific barracuda	*Sphyraena argentea*
pricklebacks	Stichaeidae
rockfishes	*Sebastes* spp.
sea basses	*Paralabrax* spp.
sculpins	*Artedius* spp., *Orthonopias triacis*
silversides	*Atherinops affinis, Atherinopsis californiensis, Leuresthes tenuis*

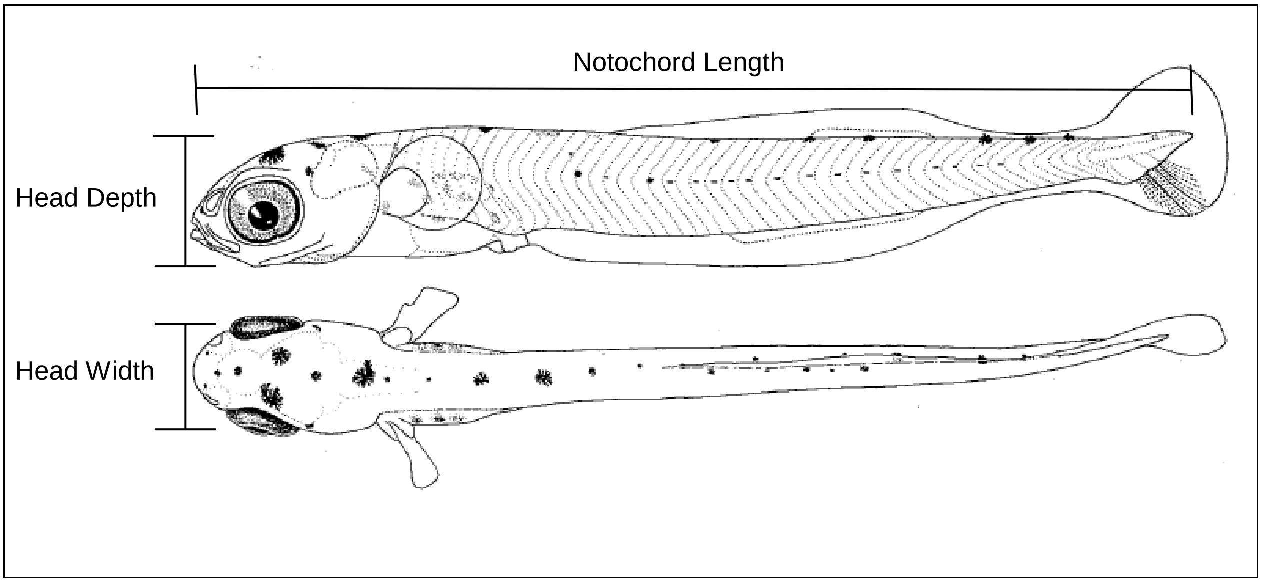

Figure 3-3 - Illustration of the location of measurements for notochord length and head depth (height) and width of a preflexion stage jacksmelt From Moser (1996).

The analysis of notochord length and head capsule dimensions in Tenera (2011) was done using nonlinear allometric regression analysis where head capsule dimension was assummed to be a power function of notochord length. This type of regression model is used to describe proportional changes in body shape with growth (e.g., Fuiman 1983, Gisbert et al. 2002, and Pena and Dumas 2009). All of the taxa were first analyzed with a single model using all of the measured specimens. However, anchovies (Engraulidae), and silversides (Atherinopsidae) showed a discontinuity in the growth relationship at lengths that corresponded approximately to the larval transformation phase or slightly smaller in the case of anchovies, when the larvae start developing into a juvenile and might begin to take on some adult characteristics (Moser 1996). Separate regression models were used for the two different stages of larval development for these taxa. For example, separate models were developed for silverside larvae smaller than 15 mm (0.59 in) NL, and those larger than that size, which approximately corresponds to the length at transformation. The appropriate model based on the size range of larvae collected at Harbor and Haynes will be used in the evaluation. The only results of the analysis in Tenera (2011) that are presented in this report are for the species identified as species of concern for Harbor and Haynes.

The set of parameter estimates from the logistic regressions from Tenera (2011) are used in this report to estimate head capsule dimensions in relation to larval length for the species of concern. In theory, individuals with head capsules larger than a specific screen mesh size would be excluded from entrainment, even if the approach vector was perpendicular (head-on) to the screen. Length-specific probabilities of entrainment were calculated for mesh sizes of 0.5 mm (0.02 in.), 0.75 mm (0.03 in.), 1 mm (0.04 in.), and 2 mm (0.08 in.) using estimates of variability around the allometric regressions from the analysis in Tenera (2011). To describe the effects of this variation on head capsule dimensions, 10,000 estimates of head width and head depth for each millimeter size class of notochord length (from a minimum up to a maximum length determined for the taxon) were computer-generated using the estimated standard errors for each regression parameter. Errors for regression parameters were assumed to be normally distributed. For each set of 10,000 values, a length-specific probability of entrainment was calculated as the proportion of larvae with head width and depth dimensions both smaller than the specified mesh size (and assuming square mesh). The 10,000 estimates were calculated 1,000 times using randomly selected values within ±0.5 mm (0.02 in.) of each length. The average probability of entrainment and standard error were calculated from the 1,000 estimates generated for each 1-mm length increment. While these probabilities were calculated for exclusion using square mesh, the results would also be generally applicable to wedgewire screen with slot widths corresponding to the four mesh sizes evaluated.

Entrainment probabilities were calculated over a size range that approximately corresponded to the range of the lengths of larvae that would be potentially affected. The minimum lengths for the taxa were based on the smallest larvae measured from the samples. The maximum was set at either 20 or 25 mm (0.79 or 0.98 in.) depending on the fish taxon. Fishes larger than 20–25 mm (0.79–0.98 in.) generally have characteristics (e.g., presence of head and opercular spines) that would likely bias entrainment probabilities based only on larval head capsule measurements. Fishes at this size also have swimming abilities that allow them to potentially avoid entrainment, especially at reduced intake velocities that could be used at plants retrofitting with fine mesh or wedge-wire screens.

The probabilities across the size range of entrainable larvae for a taxon can be used to assess the effects on population mortality when using a particular screen dimension for reducing the entrainment of larvae. Two simple assumptions to calculate the reduction of mortality are: 1) linear growth over time, and 2) constant exponential natural mortality. These assumptions are reasonable because the time period that the larvae are vulnerable to being entrained is likely to be very short. The time period may only be a few days for fishes that are only subject to entrainment over a narrow size range, but for other fishes the time period would likely never extend beyond one or two months. By assuming linear growth, length becomes directly proportional to age. As a larval cohort progresses through consecutive length classes it follows an exponential decrease in numbers over time due to natural mortality. Under these assumptions, each length (or age) would produce the same number of fishes at a length when they are not subject to entrainment. A first approximation of the reduction in entrainment for each screen mesh dimension can be made by summing the length-specific entrainment probabilities, and dividing by the number of probability estimates. The subtraction of this value from one determines the reduction of mortality for the total cohort of larvae that would survive to the length or age when they are no longer subject to entrainment. The average reduction in mortality would need to be adjusted for the composition and size structure of the fish larvae for a specific location and sample year, but otherwise it provides an estimate of the population-level mortality identical to an adult equivalent model using constant growth and survival rates extrapolated to the length or age that the fish are no longer subject to entrainment (estimated to be 20–25 mm [0.79–0.98 in.] for this analysis).

Actual entrainment estimates for Harbor and Haynes for each length were also calculated using the probabilities based on the head capsule measurements. This additional analysis required data on the size composition of the larvae. The results from the studies at Harbor and Haynes did not provide adequate data across all the size classes for this analysis so data for these five taxa from previous intake studies in southern California (Table 3-2) were used to provide a more complete data set for the analysis. The estimates were calculated for a theoretical entrainment of 100 million larvae since the percentage reductions of entrainment would apply to any intake volume assuming that the size composition of the population subject to entrainment is the same as the results presented for each taxon.

3.3 Evaluation of Fine-mesh Screen Biological Performance

There is very limited information available for post-impingement survival data for west coast larvae. Studies done at the Redondo Beach Generating Station in 1979 on larvae from six species of fishes common the southern California (California grunion, giant kelpfish, topsmelt, white croaker, northern anchovy, and shadow goby) showed that larval survival following impingement was variable among the six species and very dependent on the size of the larvae (LMS Inc. 1981). Unfortunately most of the larvae rested were much larger than the larvae collected from the entrainment studies at Harbor and Haynes. Survival estimates presented here were derived from available data from other sites with fine-mesh traveling screens or other evaluations (e.g., laboratory and pilot-scale studies). Existing field data on the species specific efficacy of fine-mesh screens with fish eggs and larvae are limited and estimates are often based on only a few data points. In such cases, data are expanded to include other members of the same genus. The underlying assumption is that fish in the same genus have similar morphology and hardiness. There were several cases where no other data within the same genus were available. In such cases, the database was further expanded to include members of the same family; or, a surrogate species from a different family was selected based on perceived similarities in fragility.

Estimates of larval survival and the surrogate species used to generate the estimates are presented in Table 3-4. Post-impingement survival of larval fish is extremely variable by species and within species (e.g., Taft et al. 1981, Brueggemeyer et al. 1988, Kuhl and Mueller 1988; Thompson 2000; LMS 1987); therefore, it is difficult to estimate *a priori* the level of survival that could be achieved at Haynes and Harbor under the site-specific characteristics at each facility.

Table 3-4 - Estimated post-impingement survival for larval and egg stages with the commonly impinged species at Haynes and Harbor Generating Stations.

Common Name	Larval Survival	Surrogate
blennies	15%	Family Gobbidae
anchovies	1%	*Anchoa mitchilli, Alosa pseudoharengus,* and *Alosa aestivalis*
gobies	15%	Family Gobbidae
white croaker	20%	*Bairdiella chrysoura* and *Micropogonias undulatus*
silverside (Haynes only)	5%	Family Atherinopsidae

3.4 Analytical methods to estimate expected overall survival performance

The overall performance of the four screen meshes at Harbor and Haynes will be estimated by combining the results from the evaluation of the screens at reducing entrainment and the information on the estimated survival of larvae that would be impinged on the screens. The estimates of the screen performance are based on the head capsule dimensions of the larvae, and assume that the larvae would be contacting the screen either head or tail first where the axis of the body is close to perpendicular to the screen surface. As a result, the estimates would be expected to provide very conservative estimates of screen performance as larger numbers of larvae are likely to be excluded than predicted. A large percentage of these larvae would also be too small to survive the processes of impingement, screenwash, and transfer associated with the fine mesh screen systems. Therefore, the integrated discussion of performance will focus on larger larvae that the results from the review of the studies indicate are likely to survive. Very low levels of survival would be expected for any larvae that are smaller than the length at which they undergo flexion of the notochord and begin development of caudal-fin rays and supporting skeletal elements. The estimated survival from the studies was applied to the lengths of flexion through transformation. The flexion and transformation lengths for the target taxa analyzed were obtained from Moser (1996).

4
RESULTS

The purpose of this chapter is to present the results of the analysis of potential biological performance of fine-mesh traveling water screens and cylindrical wedgewire screens for both Harbor and Haynes. The chapter begins with a summary of existing entrainment studies to identify the appropriate species of concern for the analysis. Results are then presented for the retention/exclusion evaluation based on the head capsule analysis for the species of concern that is applicable to both fine-mesh traveling water screens (retention) and narrow-slot cylindrical wedgewire screens (exclusion). The Chapter then considers biological performance expectations for fine-mesh traveling water screens as a result of the fish collection process and concludes with overall survival estimates for each species of concern.

4.1 Species of Concern

This section presents the results of the entrainment sampling completed at the Harbor and Haynes from January through December 2006. The species of concern were selected largely on their abundance in the entrainment studies, but are also representative of the various habitats within the intake source waters. Data summaries of the seasonal and diel variation of total entrainment at both facilities are presented to help inform decisions regarding the levels of entrainment reduction that can be achieved through the reduction of cooling water flow during the night or during times of the year when power demand is low.

4.1.1 Harbor Generating Station Entrainment Studies

A total of 26 surveys were conducted at the entrainment station (Stations E1 – Figure 3-1) between January 10 and December 18, 2006 (Table 4-1). A total of 408 entrainment samples were processed for data analysis. A total of 8,692 larval fishes representing 48 taxa were collected from the Harbor entrainment station (E1) during 26 bi-weekly surveys in 2006 (Table 4-2). Unidentified gobies (*Clevelandia*, *Ilypnus*, *Quietula* [CIQ] goby complex), yellowfin goby (*Acanthogobius flavimanus*), white croaker (*Genyonemus lineatus*), and bay goby (*Lepidogobius Lepidus*) were the four most abundant taxa and comprised nearly 90% of all specimens collected. The highest concentrations of larval fishes occurred during March 2006 and the lowest occurred in September (Figure 4-1). Larvae tended to be more abundant in samples collected at night than those collected during the day, although occasionally higher concentrations were found during the day (Figure 4-2). Damaged larval fishes that could not be positively identified comprised 1.0% of the total catch. Total annual entrainment of fish larvae during 2006 was estimated to be 65.30 million using actual CWIS flows and 153.33 million larvae using maximum design flows (Table 4-3).

Taxa discussed in detail in the Harbor final report included anchovies (*Engraulis mordax* plus Engraulidae), white croaker, combtooth blennies (*Hypsoblennius* spp.), CIQ Goby complex, yellowfin goby and bay goby. These four taxa (anchovies, white croaker, blennies, and gobies) are the species of concern at Harbor as they represented almost 96% of the total larvae collected during the study. These taxa are also representative of the habitats within the Harbor source waters and include fishes, such as anchovies and white croaker, which do have some commercial and recreational fisheries value.

Table 4-1 - Survey dates for entrainment sampling at the Harbor Generating Station from January 2006 through December 2006.

Survey Number	Date	Number Collected	Number Processed
HGSEA01	1/10/06	16	16
HGSEA02	1/23/06	16	16
HGSEA03	2/7/06	16	16
HGSEA04	2/21/06	16	16
HGSEA05	3/8/06	16	15 [a]
HGSEA06	3/20/06	16	16
HGSEA07	4/3/06	16	16
HGSEA08	4/17/06	16	16
HGSEA09	5/1/06	16	16
HGSEA10	5/15/06	16	16
HGSEA11	5/30/06	16	16
HGSEA12	6/12/06	16	16
HGSEA13	6/26/06	16	16
HGSEA14	07/12/06	16	16
HGSEA15	07/24/06	16	15 [a]
HGSEA16	08/07/06	16	16
HGSEA17	08/21/06	16	16
HGSEA18	09/05/06	16	14 [b]
HGSEA19	09/18/06	16	16
HGSEA20	10/02/06	16	16
HGSEA21	10/16/06	16	16
HGSEA22	10/30/06	16	16
HGSEA23	11/13/06	16	16
HGSEA24	11/29/06	16	16
HGSEA25	12/11/06	16	16
HGSEA26	12/26/06	12 [c]	12
	TOTAL	**412**	**408**

[a] *One sample from Station E1 was not preserved properly and could not be processed.*
[b] *Two samples were lost (spilled) in transit (Stations H4 & H5).*
[c] *One complete cycle (4 samples) was not collected due to adverse sea conditions.*

Table 4-2 - Average concentration of larval fishes in entrainment samples collected at the Harbor Generating Station from January 2006 through December 2006.

Taxon	Common Name	Avg. Conc. (per 1,000 m^3)	Total Count	Percentage of Total	Cumulative Percentage
Gobiidae unid.	CIQ gobies	516.10	4,340	49.32	49.32
Acanthogobius flavimanus	yellowfin goby	263.17	2,068	25.15	74.47
Genyonemus lineatus	white croaker	125.26	1,090	11.97	86.44
Lepidogobius lepidus	bay goby	34.02	294	3.25	89.70
Hypsoblennius spp.	combtooth blennies	29.63	239	2.83	92.53
Sciaenidae unid.	croakers	19.36	161	1.85	94.38
Engraulidae unid.	anchovies	13.97	114	1.33	95.71
unidentified larvae	unidentified damaged	10.51	90	1.00	96.72
unidentified larvae, yolksac	unidentified yolksac larvae	4.58	37	0.44	97.15
Gillichthys mirabilis	longjaw mudsucker	3.70	38	0.35	97.51
Gobiesocidae unid.	clingfishes	3.49	28	0.33	97.84
Icelinus spp.	sculpins	2.93	25	0.28	98.12
Paralichthys californicus	California halibut	2.83	25	0.27	98.39
Paralabrax spp.	sea basses	1.96	16	0.19	98.58
Cheilotrema saturnum	black croaker	1.45	13	0.14	98.72
Seriphus politus	queenfish	1.23	10	0.12	98.84
Gibbonsia spp.	clinid kelpfishes	1.17	9	0.11	98.95
Leptocottus armatus	Pacific staghorn sculpin	1.13	8	0.11	99.06
Semicossyphus pulcher	California sheephead	1.01	8	0.10	99.15
Rhinogobiops nicholsii	blackeye goby	0.96	8	0.09	99.24
larval/post-larval fish unid.	larval fishes	0.79	7	0.08	99.32
Citharichthys spp.	sanddabs	0.76	6	0.07	99.39
Clinocottus spp.	sculpins	0.67	10	0.06	99.46
Pleuronichthys guttulatus	diamond turbot	0.61	6	0.06	99.52
Pleuronichthys spp.	turbots	0.50	4	0.05	99.56
Labrisomidae unid.	labrisomid blennies	0.47	4	0.05	99.61
Oxyjulis californica	senorita	0.37	3	0.04	99.64
Pleuronectidae unid.	righteye flounders	0.36	3	0.03	99.68
Ruscarius creaseri	roughcheek sculpin	0.32	3	0.03	99.71
Pleuronectiformes unid.	flatfishes	0.25	2	0.02	99.73
Clupeidae unid.	herrings	0.25	2	0.02	99.76
Orthonopias triacis	snubnose sculpin	0.23	2	0.02	99.78
Lythrypnus zebra	zebra goby	0.23	2	0.02	99.80
Cottidae unid.	sculpins	0.21	2	0.02	99.82
Sardinops sagax	Pacific sardine	0.20	2	0.02	99.84
Typhlogobius californiensis	blind goby	0.19	1	0.02	99.86
Roncador stearnsii	spotfin croaker	0.14	1	0.01	99.87
Merluccius productus	Pacific hake	0.14	1	0.01	99.89
Syngnathus spp.	pipefishes	0.14	1	0.01	99.90
Paralichthyidae unid.	sand flounders	0.14	1	0.01	99.91
Girella nigricans	opaleye	0.13	1	0.01	99.93

(table continued)

Table 4-2 (continued) - Average concentration of larval fishes in entrainment samples collected at the Harbor Generating Station from January 2006 through December 2006.

Taxon	Common Name	Avg. Conc. (per 1,000 m^3)	Total Count	Percentage of Total	Cumulative Percentage
Pleuronichthys verticalis	hornyhead turbot	0.13	1	0.01	99.94
Chitonotus / Icelinus	sculpins	0.13	1	0.01	99.95
Artedius spp.	sculpins	0.12	1	0.01	99.96
Bathymasteridae unid.	ronquils	0.11	1	0.01	99.97
Atherinopsidae unid.	silversides	0.10	1	0.01	99.98
Bathylagidae unid.	blacksmelt	0.10	1	0.01	99.99
Lythrypnus spp.	gobies	0.08	1	0.01	100.00
	Total Larval Fish	**1,046.36**	**8,692**		

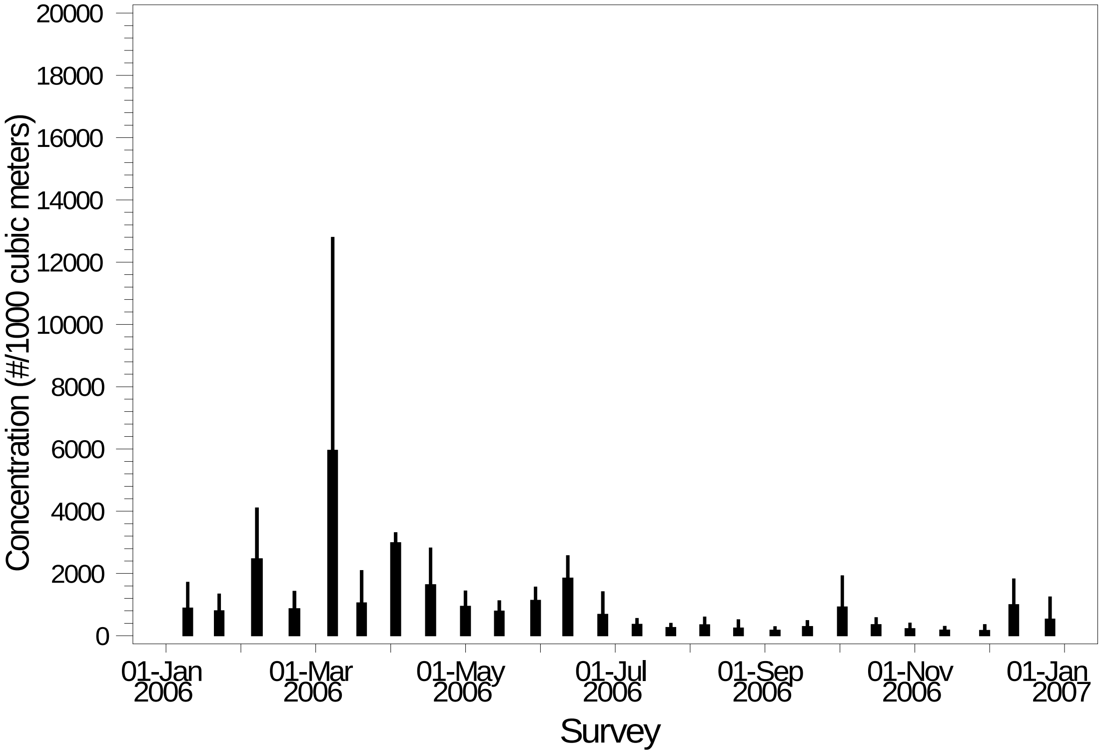

Figure 4-1 - Average concentration (#/1,000 m3 [264,172 gal] - wide bars) and standard deviation (narrow bars) of all larval fishes collected during entrainment sampling at the Harbor Generating Station from January 2006 through December 2006.

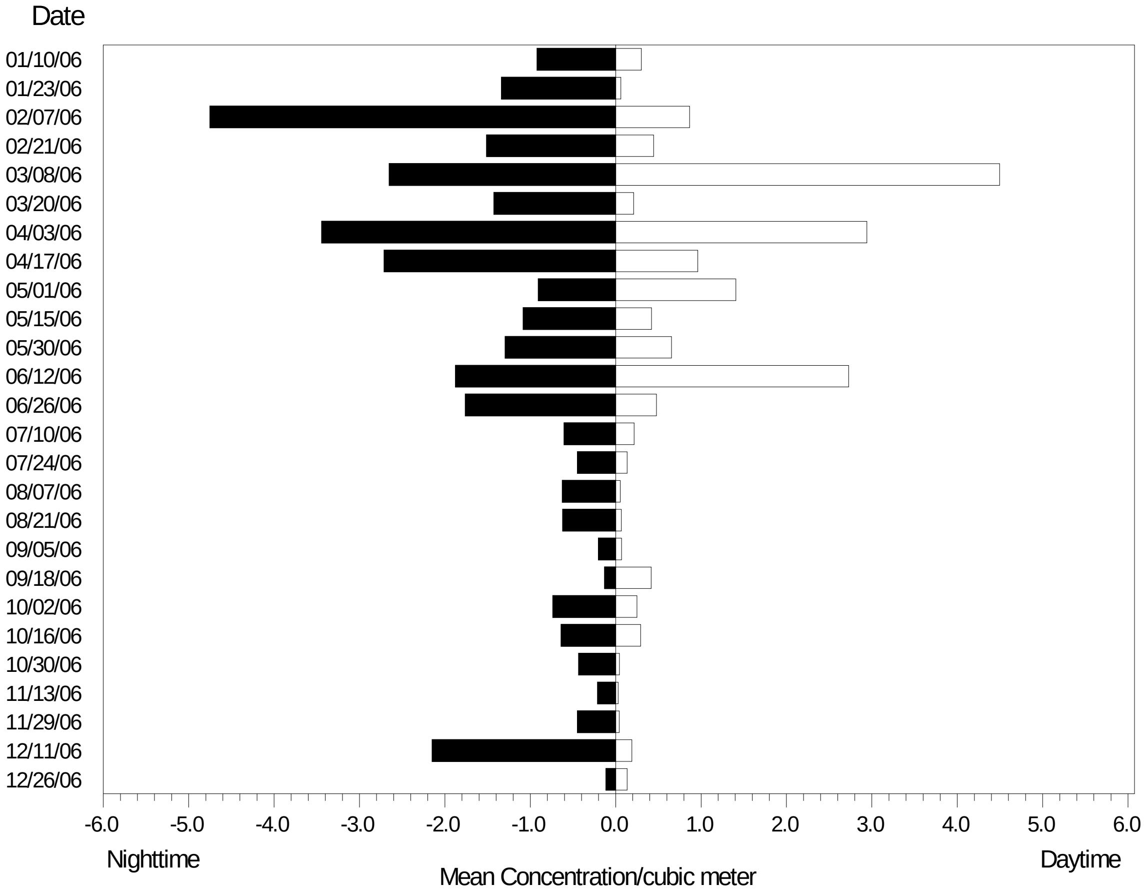

Figure 4-2 - Average concentration (#/ m^3) of all larval fishes collected during daylight (light bars) and nighttime (dark bars) entrainment sampling at the Harbor Generating Station from January 2006 through December 2006. Note: the negative values at night are an artifact of the plotting routine.

Table 4-3 - Calculated total annual entrainment of larval fishes at the Harbor Generating Station in 2006 based on actual and design (maximum) cooling water intake pump flows.

Taxon	**Common Name**	**Estimated Annual Entrainment (Actual Flows)**	**Estimated Annual Entrainment (Design Flows)**
Gobiidae unid.	gobies	33,290,815	75,938,007
Acanthogobius flavimanus	yellowfin goby	15,407,999	37,604,336
Genyonemus lineatus	white croaker	7,164,843	18,777,752
Lepidogobius Lepidus	bay goby	2,376,260	5,070,071
Hypsoblennius spp.	combtooth blennies	2,255,907	4,362,576
Sciaenidae unid.	croakers	995,438	2,856,932
Engraulidae unid.	anchovies	940,784	2,068,979
unidentified fish, damaged	unidentified damaged fish	646,175	1,571,226
larvae, unidentified Yolksac	unidentified yolksac larvae	288,308	679,015
Gillichthys mirabilis	longjaw mudsucker	254,865	558,887

Table 4-3 (continued) - Calculated total annual entrainment of larval fishes at Harbor Generating Station in 2006 based on actual and design (maximum) cooling water intake pump flows.

Taxon	Common Name	Estimated Annual Entrainment (Actual Flows)	Estimated Annual Entrainment (Design Flows)
Gobiesocidae unid.	clingfishes	236,654	515,917
Icelinus spp.	sculpins	190,484	446,021
Paralichthys californicus	California halibut	165,782	424,529
Paralabrax spp.	sand bass	122,010	271,192
Cheilotrema saturnum	black croaker	94,525	200,992
Seriphus politus	queenfish	83,731	176,487
Gibbonsia spp.	clinid kelpfishes	77,308	173,122
Rhinogobiops nicholsii	blackeye goby	71,631	145,314
Leptocottus armatus	Pacific staghorn sculpin	68,768	160,195
Semicossyphus pulcher	California sheephead	64,438	141,346
larval/post-larval fish unid.	larval fishes	58,152	119,578
Clinocottus spp.	sculpins	55,826	112,731
Citharichthys spp.	sanddabs	41,222	115,405
Pleuronichthys spp.	turbots	36,951	73,078
Pleuronichthys guttulatus	diamond turbot	36,799	93,021
Labrisomidae unid.	labrisomid blennies	29,483	71,609
Oxyjulis californica	senorita	24,673	52,620
Pleuronectidae unid.	righteye flounders	23,120	52,521
Ruscarius creaseri	roughcheek sculpin	20,616	50,242
Pleuronectiformes unid.	flatfishes	16,347	40,493
Cottidae unid.	sculpins	15,756	31,607
Lythrypnus zebra	zebra goby	14,795	34,416
Syngnathus spp.	pipefishes	14,250	20,766
Orthonopias triacis	snubnose sculpin	13,806	32,367
Sardinops sagax	Pacific sardine	11,836	29,933
Artedius spp.	sculpins	10,653	17,916
Typhlogobius californiensis	blind goby	10,523	26,455
Clupeidae unid.	herrings	8,864	36,966
Roncador stearnsii	spotfin croaker	8,735	21,531
Pleuronichthys verticalis	hornyhead turbot	8,693	19,596
Merluccius productus	Pacific hake	8,421	19,741
Girella nigricans	opaleye	7,894	19,963
Bathylagidae unid.	blacksmelt	6,622	14,928
Lythrypnus spp.	gobies	6,249	11,481
Bathymasteridae unid.	ronquils	5,843	14,511
Paralichthyidae unid.	sand flounders	1,926	20,449
Chitonotus / Icelinus	sculpins	1,798	19,097
Atherinopsidae unid.	silversides	1,422	15,096
	Total Larval Fish	**65,298,000**	**153,331,013**

4.1.2 Haynes Generating Station Entrainment Studies

A total of 26 surveys were conducted at the entrainment station (Stations E3 – Figure 3-2) between January 5 and December 23, 2006 (Table 4-4). A total of 12,651 entrainable fish larvae from 35 separate taxonomic categories were collected from the 208 samples collected during the surveys (Table 4-5). The most abundant larval fish taxon in the samples was unidentified gobies, which comprised 51.3% of the total larvae collected, followed by silversides (23.9%) and combtooth blennies (20.1%). Densities of fish larvae peaked in late May at an average concentration of approximately 17,000 per 1,000 m^3 (264,172 gal) (Figure 4-3). Larvae were substantially more abundant in samples collected at night than those collected during the day in nearly every survey (Figure 4-4). Total annual entrainment was estimated to be 3.65 billion fish larvae during 2006 using the Haynes CWIS actual flows as the basis for calculations (Table 4-6) and 4.53 billion fish larvae using the design (maximum capacity) CWIS flows.

Taxa discussed in detail in the Haynes final report included anchovies, silversides (Atherinopsidae), white croaker, combtooth blennies (*Hypsoblennius* spp.), and CIQ Goby complex. These five taxa groups (anchovies, silversides, croakers, blennies, and gobies) are the species of concern at the Haynes as they represent almost 98% of the total larvae collected during the study. These taxa are also representative of the habitats within the Haynes source waters and include fishes, such as anchovies and white croaker, which do have some commercial and recreational fisheries value.

Table 4-4 - Survey dates for entrainment sampling at the Haynes Generating Station. Eight samples were collected and processed from each survey.

Survey Number	Date	Survey Number	Date
HGSEA01	1/5/06	HGSEA14	7/05/06
HGSEA02	1/17/06	HGSEA15	7/17/06
HGSEA03	1/31/06	HGSEA16	7/31/06
HGSEA04	2/14/06	HGSEA17	8/14/06
HGSEA05	2/27/06	HGSEA18	8/28/06
HGSEA06	3/13/06	HGSEA19	9/11/06
HGSEA07	3/26/06	HGSEA20	9/25/06
HGSEA08	4/10/06	HGSEA21	10/09/06
HGSEA09	4/24/06	HGSEA22	10/23/06
HGSEA10	5/8/06	HGSEA23	11/06/06
HGSEA11	5/22/06	HGSEA24	11/20/06
HGSEA12	6/5/06	HGSEA25	12/04/06
HGSEA13	6/19/06	HGSEA26	12/18/06

Table 4-5 - Average concentration of larval fishes and fish eggs in entrainment samples collected at Haynes Generating Station (Station E3) from January 2006 through December 2006.

Taxon	Common Name	Avg. Conc. (per 1,000 m^3)	Total Count	Percentage of Total	Cumulative Percentage
Gobiidae unid.	gobies	1,667.51	6,354	51.31	51.31
Atherinopsidae unid.	silversides	778.19	3,263	23.94	75.25
Hypsoblennius spp.	combtooth blennies	651.69	2,444	20.05	95.31
Genyonemus lineatus	white croaker	67.68	267	2.08	97.39
Engraulidae unid.	anchovies	19.54	76	0.60	97.99
Labrisomidae unid.	labrisomid blennies	14.11	52	0.43	98.42
Gobiesocidae unid.	clingfishes	8.33	32	0.26	98.68
unidentified fish, damaged	unid. damaged fish	8.04	30	0.25	98.93
Sciaenidae unid.	croakers	6.54	25	0.20	99.13
Gibbonsia spp.	clinid kelpfishes	3.86	14	0.12	99.25
Syngnathus spp.	pipefishes	2.57	10	0.08	99.33
Pleuronichthys guttulatus	diamond turbot	2.33	9	0.07	99.40
larvae, unidentified yolksac	unidentified yolksac larvae	2.18	8	0.07	99.46
Seriphus politus	queenfish	2.10	8	0.06	99.53
Acanthogobius flavimanus	yellowfin goby	2.05	8	0.06	99.59
Gillichthys mirabilis	longjaw mudsucker	1.83	7	0.06	99.65
Typhlogobius californiensis	blind goby	1.78	7	0.05	99.70
larval/post-larval fish unid.	larval fishes	1.32	5	0.04	99.74
Paralichthys californicus	California halibut	1.09	4	0.03	99.78
Leptocottus armatus	Pacific staghorn sculpin	1.07	4	0.03	99.81
Hypsypops rubicundus	garibaldi	1.01	4	0.03	99.84
Citharichthys spp.	sanddabs	0.74	3	0.02	99.86
Rhinogobiops nicholsii	blackeye goby	0.59	2	0.02	99.88
Cheilotrema saturnum	black croaker	0.53	2	0.02	99.90
Umbrina roncador	yellowfin croaker	0.52	2	0.02	99.91
Pleuronectidae unid.	righteye flounders	0.30	1	0.01	99.92
Haemulidae unid.	grunts	0.28	1	0.01	99.93
Xenistius californiensis	salema	0.28	1	0.01	99.94
Paralabrax spp.	sand bass	0.28	1	0.01	99.95
Chaenopsidae unid.	tube blennies	0.25	1	0.01	99.96
Roncador stearnsii	spotfin croaker	0.25	1	0.01	99.97
Stenobrachius leucopsarus	northern lampfish	0.24	1	0.01	99.97
Parophrys vetulus	English sole	0.23	1	0.01	99.98
Sardinops sagax	Pacific sardine	0.23	1	0.01	99.99
Clupeiformes unid.	herrings and anchovies	0.22	1	0.01	99.99
Merluccius productus	Pacific hake	0.22	1	0.01	100.00
	Total Larval Fish	**3,249.97**	**12,651**		

Table 4-6 - Calculated total annual entrainment of larval fishes and fish eggs at Haynes Generating Station from January 2006 through December 2006 based on actual and design cooling water intake pump flows.

Taxon	Common Name	Estimated Annual Entrainment (Actual Flows)	Estimated Annual Entrainment (Design Flows)
Gobiidae unid.	gobies	1,828,364,516	2,334,220,376
Atherinopsidae unid.	silversides	920,323,104	1,062,818,072
Hypsoblennius spp.	combtooth blennies	732,022,349	915,313,887
Genyonemus lineatus	white croaker	75,425,299	96,188,344
Engraulidae unid.	anchovies	22,673,541	27,301,289
Labrisomidae unid.	labrisomid blennies	15,068,186	19,493,190
Gobiesocidae unid.	clingfishes	9,088,713	11,712,226
unidentified fish, damaged	unidentified damaged fish	8,705,487	11,578,027
Sciaenidae unid.	croakers	7,187,066	9,313,532
Gibbonsia spp.	clinid kelpfishes	3,583,074	5,590,130
Syngnathus spp.	pipefishes	3,111,275	3,765,987
Pleuronichthys guttulatus	diamond turbot	2,664,083	3,409,219
Seriphus politus	queenfish	2,490,643	2,937,768
larvae, unidentified yolksac	unidentified yolksac larvae	2,415,796	3,051,218
Acanthogobius flavimanus	yellowfin goby	2,024,413	2,715,310
Gillichthys mirabilis	longjaw mudsucker	1,977,286	2,550,861
Typhlogobius californiensis	blind goby	1,961,918	2,453,304
larval/post-larval fish unid.	larval fishes	1,184,545	1,620,620
Paralichthys californicus	California halibut	1,153,745	1,520,648
Hypsypops rubicundus	garibaldi	985,374	1,381,248
Leptocottus armatus	Pacific staghorn sculpin	876,157	1,491,536
Citharichthys spp.	sanddabs	821,712	1,026,911
Rhinogobiops nicholsii	blackeye goby	703,083	823,133
Cheilotrema saturnum	black croaker	626,312	764,490
Umbrina roncador	yellowfin croaker	506,822	721,836
Pleuronectidae unid.	righteye flounders	385,901	414,783
Haemulidae unid.	grunts	375,837	396,576
Xenistius californiensis	salema	375,837	396,576
Paralabrax spp.	sand bass	359,420	388,533
Roncador stearnsii	spotfin croaker	332,942	351,314
Stenobrachius leucopsarus	northern lampfish	268,400	332,364
Parophrys vetulus	English sole	260,975	323,169
Sardinops sagax	Pacific sardine	255,242	319,095
Clupeiformes unid.	herrings and anchovies	243,832	301,941
Merluccius productus	Pacific hake	243,832	301,941
Chaenopsidae unid.	tube blennies	161,673	354,629
	Total Larval Fish	**3,649,208,392**	**4,527,644,084**

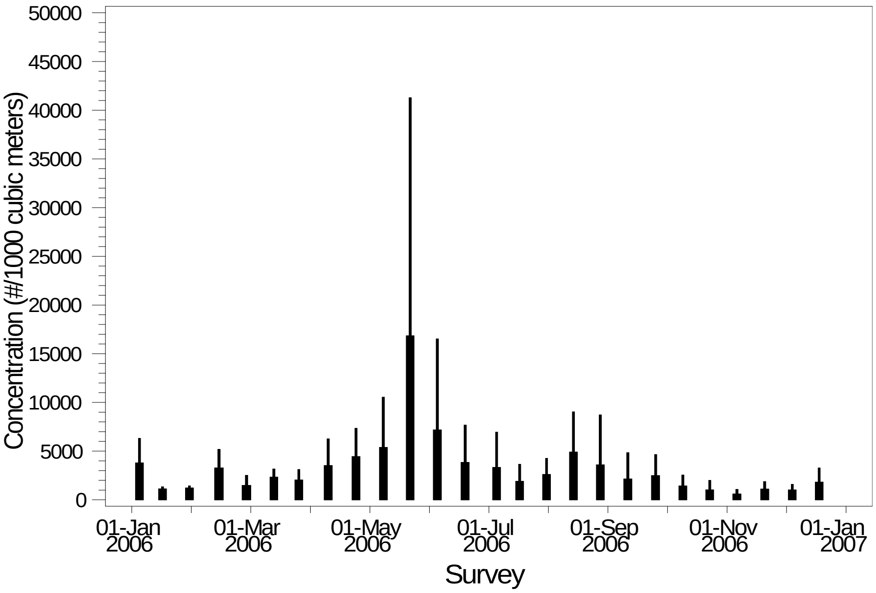

Figure 4-3 - Mean concentration (# / 1,000 m^3 [264,172 gal] – wide bars) and standard deviation (narrow bars) of all larval fishes collected at the intake station (E3) during entrainment sampling at the Haynes Generating Station in 2006.

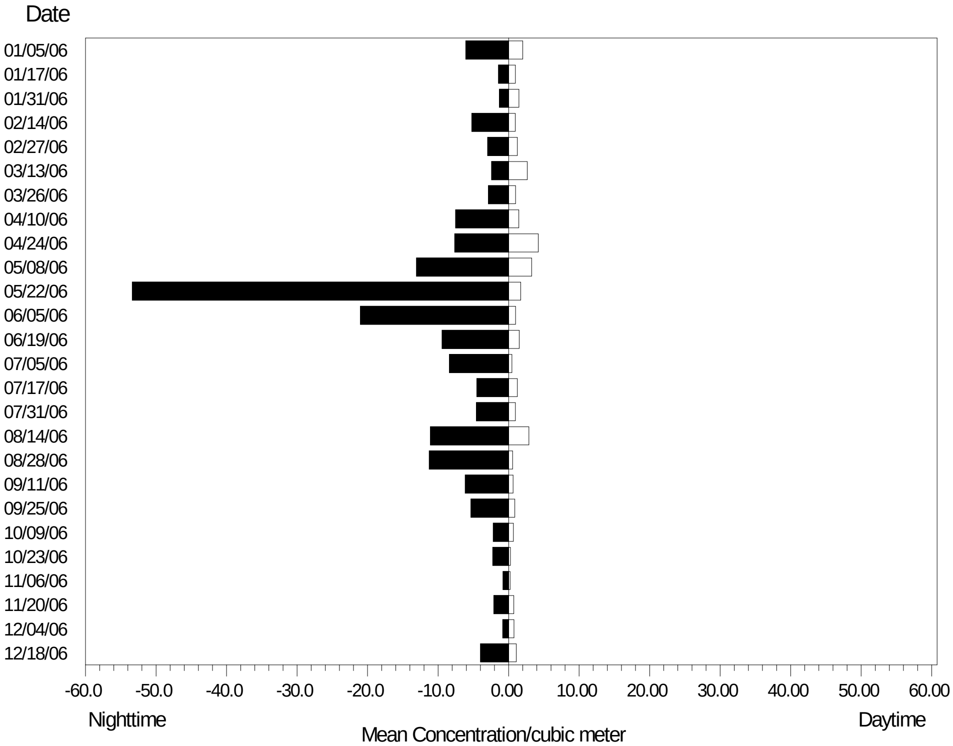

Figure 4-4 - Average concentration (#/ m^3) of all larval fishes collected during daylight (light bars) and nighttime (dark bars) entrainment sampling at the Haynes Generating Station from January 2006 through December 2006. Note: the negative values at night are an artifact of the plotting routine.

4.2 Results of Analysis of Retention (Applicable to Fine-mesh Screens) and Exclusion (Applicable to Narrow-slot Wedgewire Screens)

Head capsule width is employed as the method to estimate retention on fine-mesh traveling water screens and exclusion from entrainment into narrow-slot cylindrical wedgewire screens as discussed in Chapter 3.

4.2.1 Estimates of Retention (Fine-mesh Screens) and Exclusion (Narrow-slot Wedgewire Screens for Species of Concern

Summary data for the fishes used in the allometric regression analysis are presented in Table 4-7. The statistics and parameters resulting from the allometric regressions from Tenera (2011) are shown in Table 4-8, and dispersion plots of the data for each of the five taxa are shown in Figures 4-5 through 4-11, which were also presented in Tenera (2011). The results for anchovies (Figure 4-5), and silversides (Figure 4-8) showed discontinuities. The discontinuity for silversides approximately corresponded to the length of larval transformation of 15 mm (0.59 in.) reported by Moser (1996). The anchovies measured for this study appear to have a growth inflection at about 19 mm (0.75 in), which is less than the reported transformation size for northern anchovy (Moser 1996). Separate calculations for both growth phases (smaller and larger-sized groups) were calculated for anchovies and silversides, and these relationships are plotted in the figures that follow the models for the entire length range. The same approach was used by Gisbert et al. (2002), and Pena and Dumas (2009), in their analyses of allometric growth patterns in California halibut and spotted sand bass larvae, respectively.

Table 4-7 - Summary data on length and head capsule dimensions for the larvae used in allometric regression analysis.

Common Name	N	Length (mm)					Head Depth (mm)					Head Width (mm)				
		Mean	Max	Min	Median	Std. Dev.	Mean	Max	Min	Median	Std. Dev.	Mean	Max	Min	Median	Std. Dev.
anchovies	282	14.10	31.01	1.51	14.23	8.1962	1.15	3.49	0.15	0.95	0.8155	1.16	3.10	0.19	1.13	0.6721
silversides	221	12.28	31.07	3.63	11.01	5.7681	1.54	4.37	0.34	1.14	0.9533	1.42	3.70	0.35	1.15	0.7105
croakers	167	5.18	14.87	1.23	4.18	3.5911	1.29	4.31	0.15	0.89	1.0339	0.94	3.21	0.20	0.73	0.6911
combtooth blennies	42	2.54	4.31	1.87	2.25	0.6579	0.49	1.10	0.35	0.44	0.1445	0.42	0.89	0.32	0.39	0.1152
gobies	204	7.88	22.14	1.90	6.46	4.9773	1.04	3.44	0.31	0.78	0.6885	0.92	3.90	0.25	0.71	0.6301

Table 4-8 - Allometric regression parameter statistics ($y=ax^b$) and standard errors describing the sample composition of each taxon used in the analysis, where x = notochord length (mm). All stages (sizes) were used unless noted.

	Y Variable: Head Depth (Height)				Y Variable: Head Width			
Taxon	a	SE(a)	b	SE(b)	a	SE(a)	b	SE(b)
anchovies - all	0.0215	0.0023	1.4524	0.0342	0.0776	0.0046	1.0167	0.0195
≤ 19 mm	0.0964	0.0062	0.8739	0.0247	0.1202	0.0054	0.8461	0.0173
≥ 19 mm	0.0104	0.0035	1.6831	0.1037	0.0216	0.0054	1.4184	0.0784
silversides	0.0588	0.0035	1.2880	0.0206	0.1006	0.0038	1.0531	0.0135
≤ 15 mm	0.0908	0.0060	1.0730	0.0280	0.1328	0.0073	0.9219	0.0236
≥ 15 mm	0.1400	0.0220	1.0089	0.0520	0.1394	0.0171	0.9490	0.0406
croakers	0.2094	0.0129	1.0979	0.0276	0.1894	0.0148	0.9783	0.0356
combtooth blennies	0.1833	0.0160	1.0427	0.0814	0.1777	0.0166	0.9231	0.0884
gobies	0.1100	0.0073	1.0735	0.0258	0.0890	0.0068	1.1123	0.0297

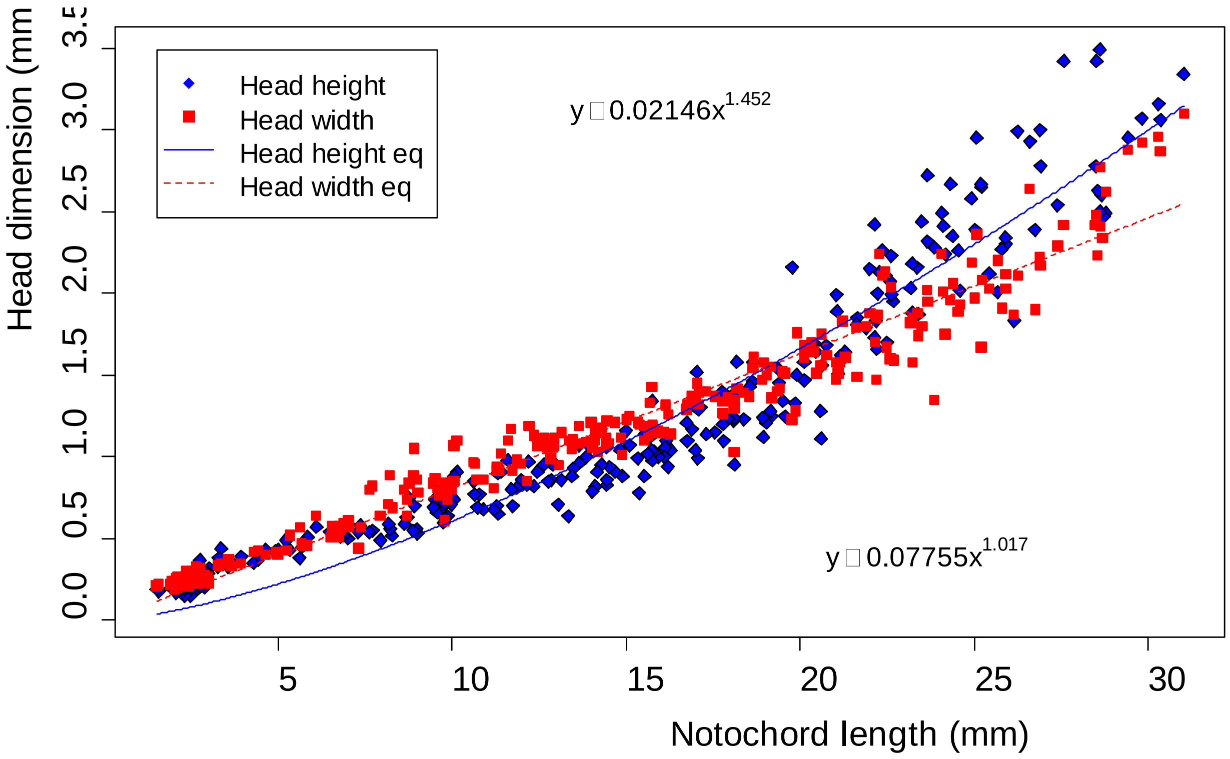

Figure 4-5 - Allometric regression plot for all lengths of anchovies (Engraulidae and Engraulis mordax).

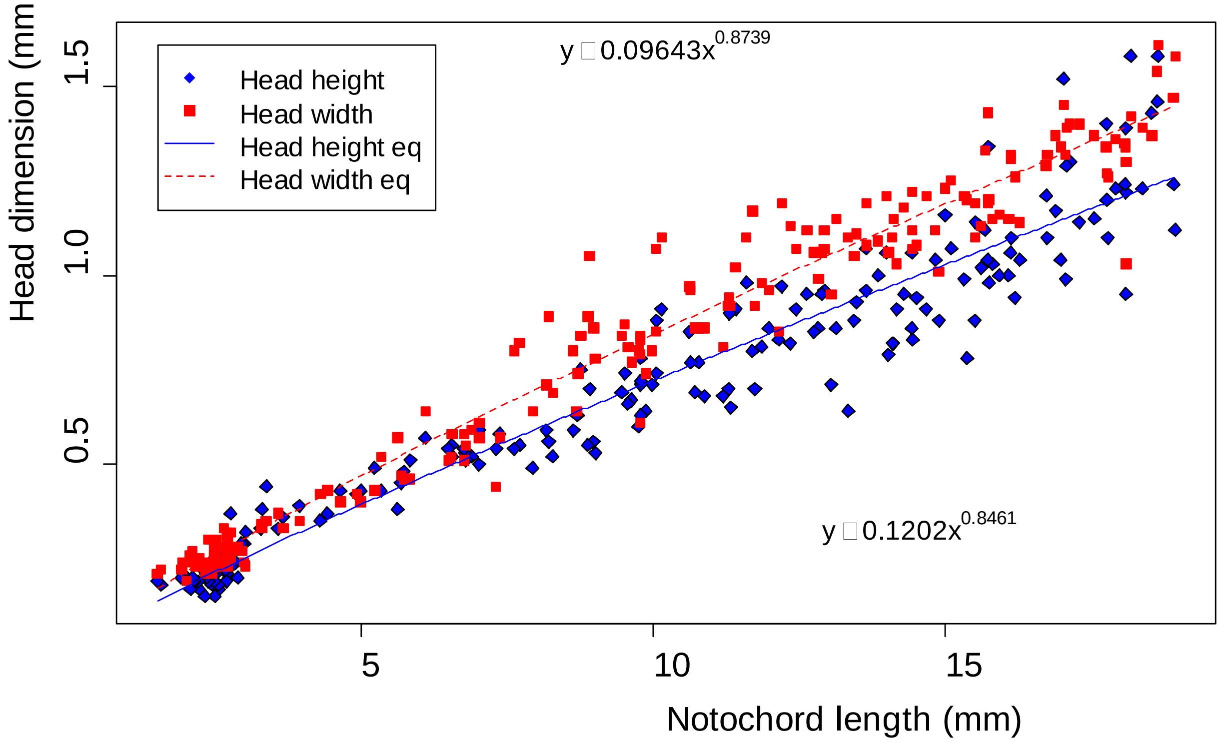

Figure 4-6 - Allometric regression plot for anchovy (Engraulidae and Engraulis mordax) larvae less than or equal to 19 mm (0.75 in.) notochord length.

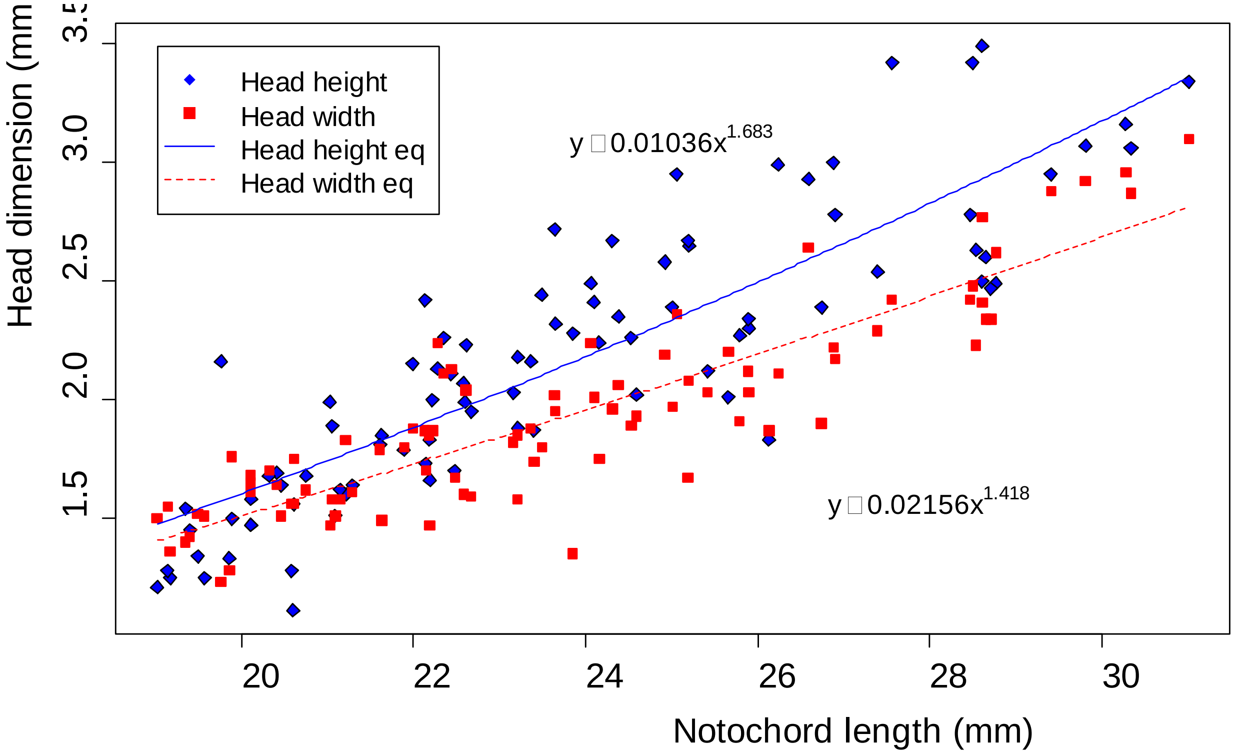

Figure 4-7 - Allometric regression plot for anchovy (Engraulidae and Engraulis mordax) larvae equal to or greater than 19 mm (0.75 in.) notochord length.

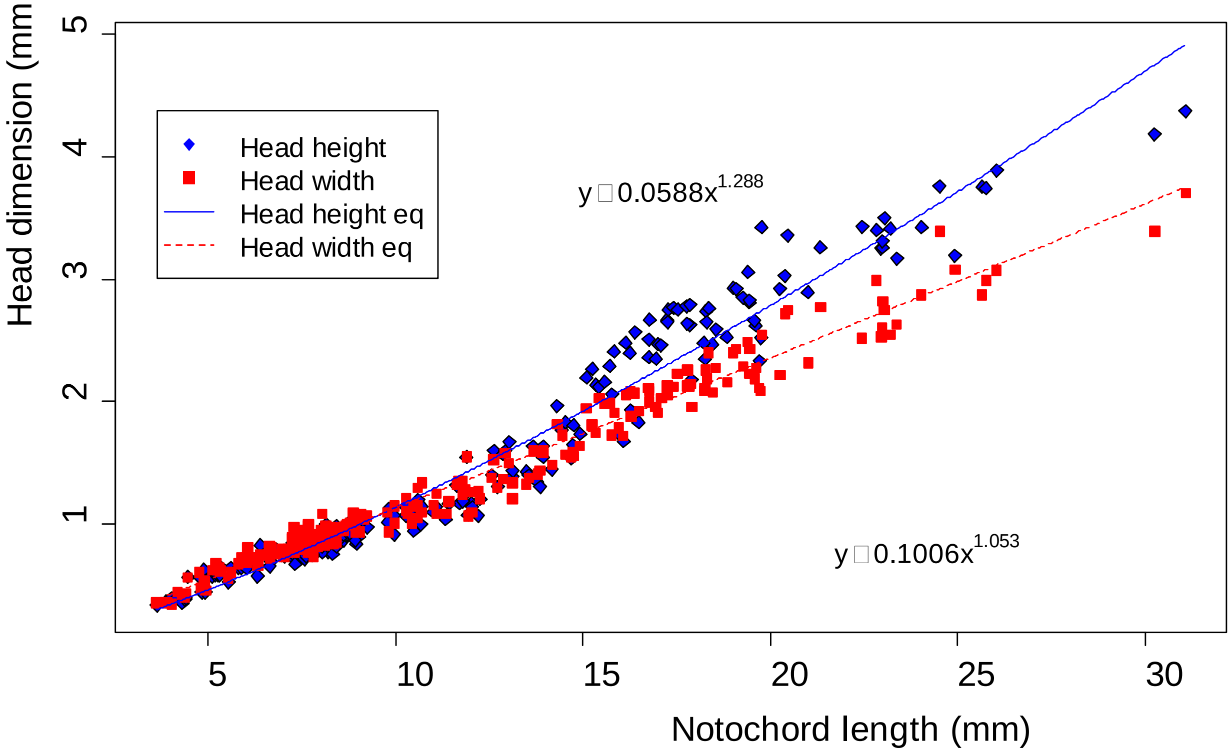

Figure 4-8 - Allometric regression plot for all lengths of silverside (Family Atherinopsidae) larvae.

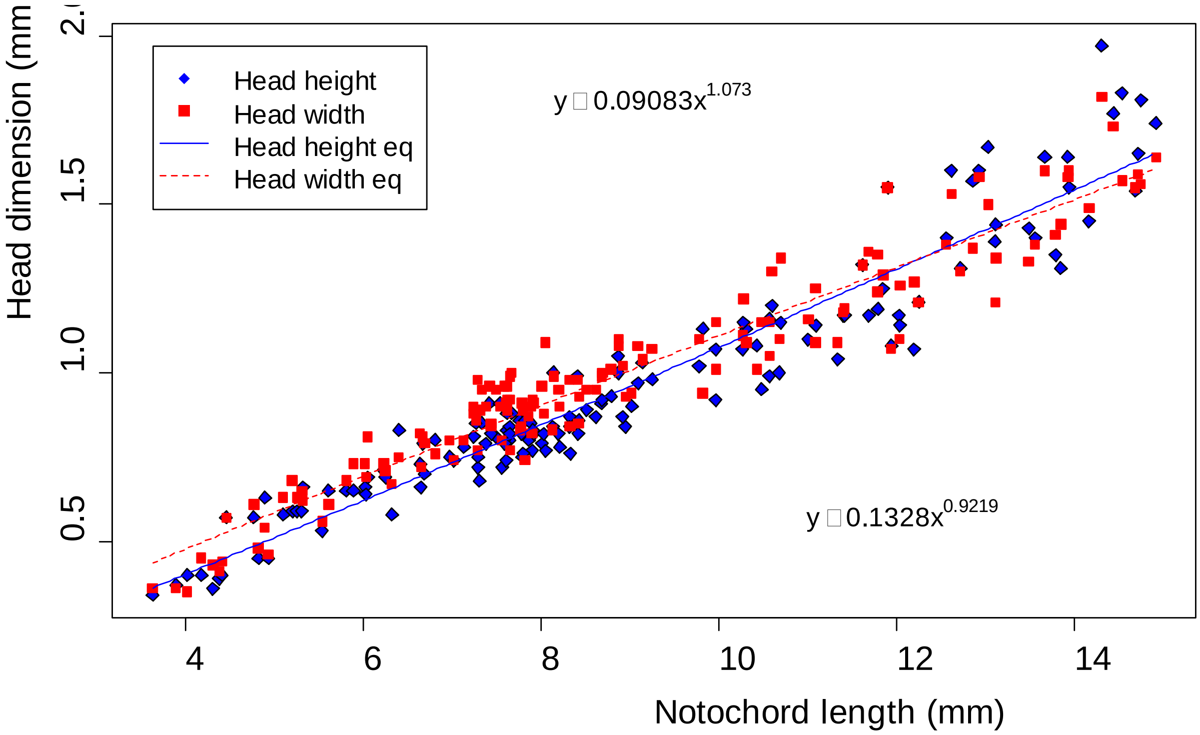

Figure 4-9 - Allometric regression plot for silverside (Family Atherinopsidae) larvae less than or equal to 15 mm (0.59 in.) notochord length.

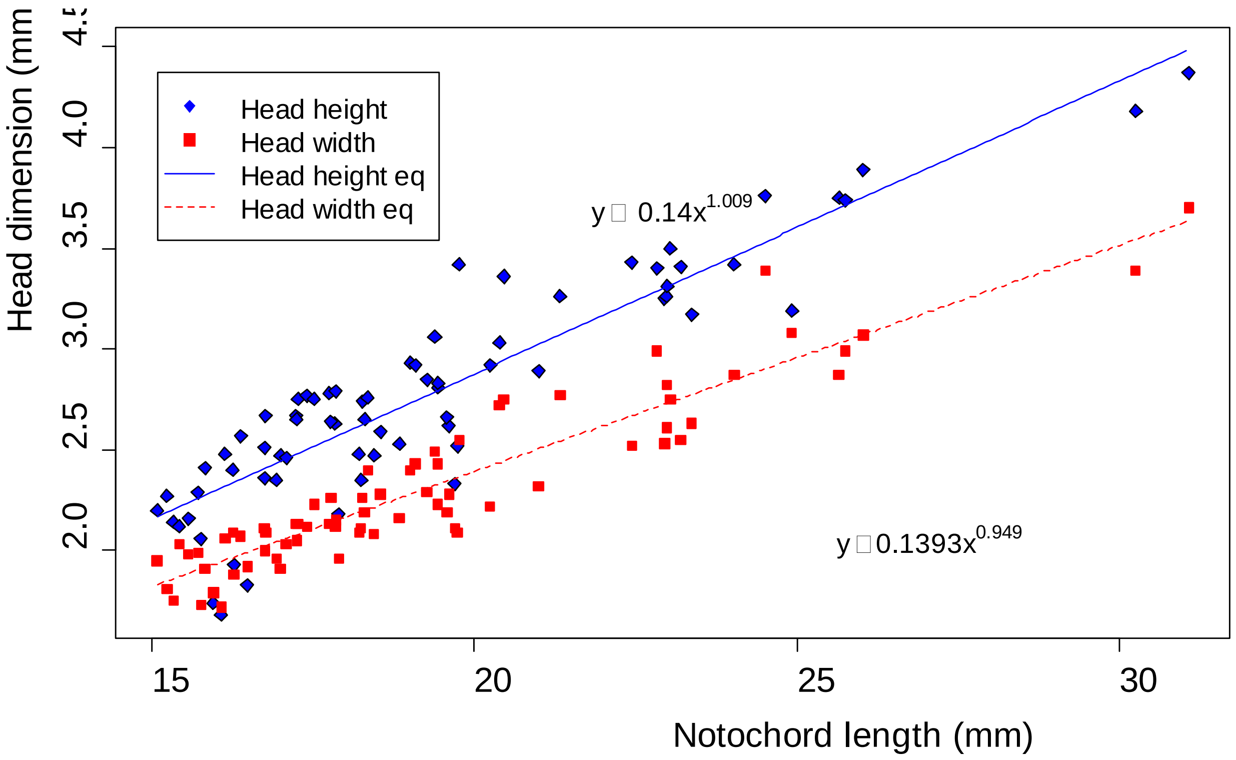

Figure 4-10 - Allometric regression plot for silverside (Family Atherinopsidae) larvae greater than or equal to 15 mm (0.59 in.) notchord length.

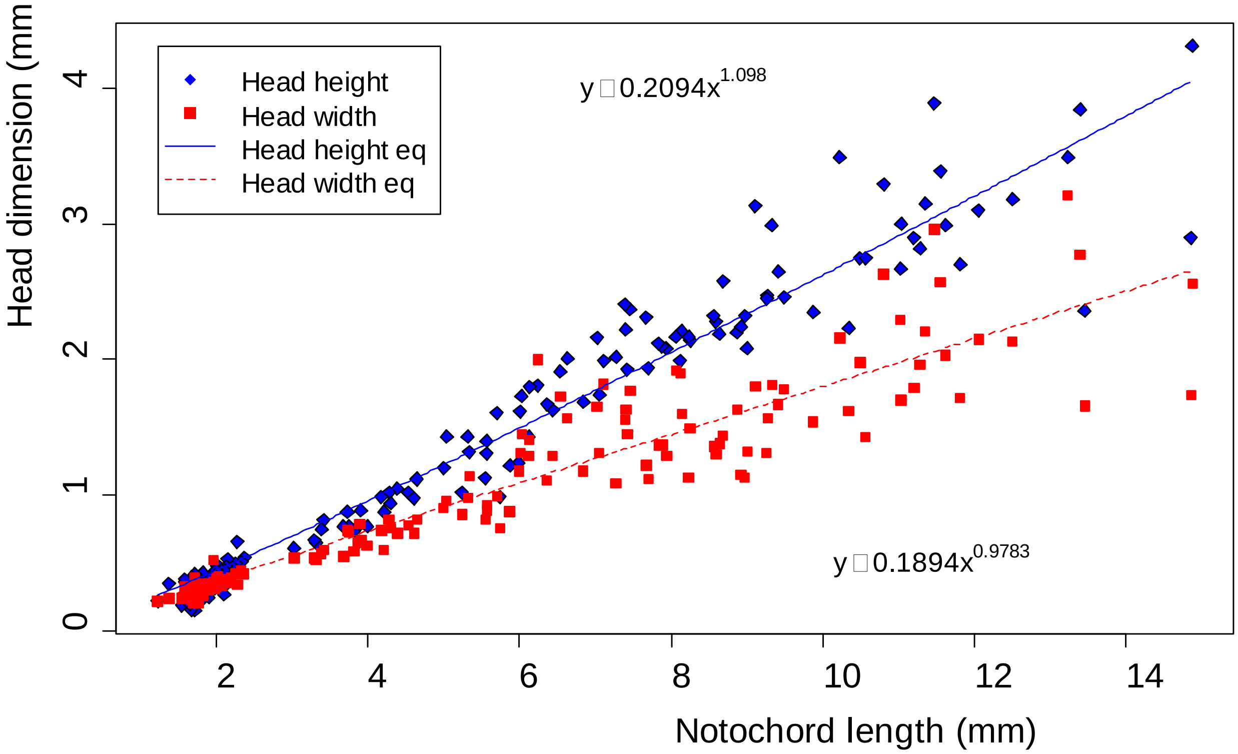

Figure 4-11 - Allometric regression plot for all lengths of croaker (*Seriphus politus* and *Genyonemus lineatus*) larvae.

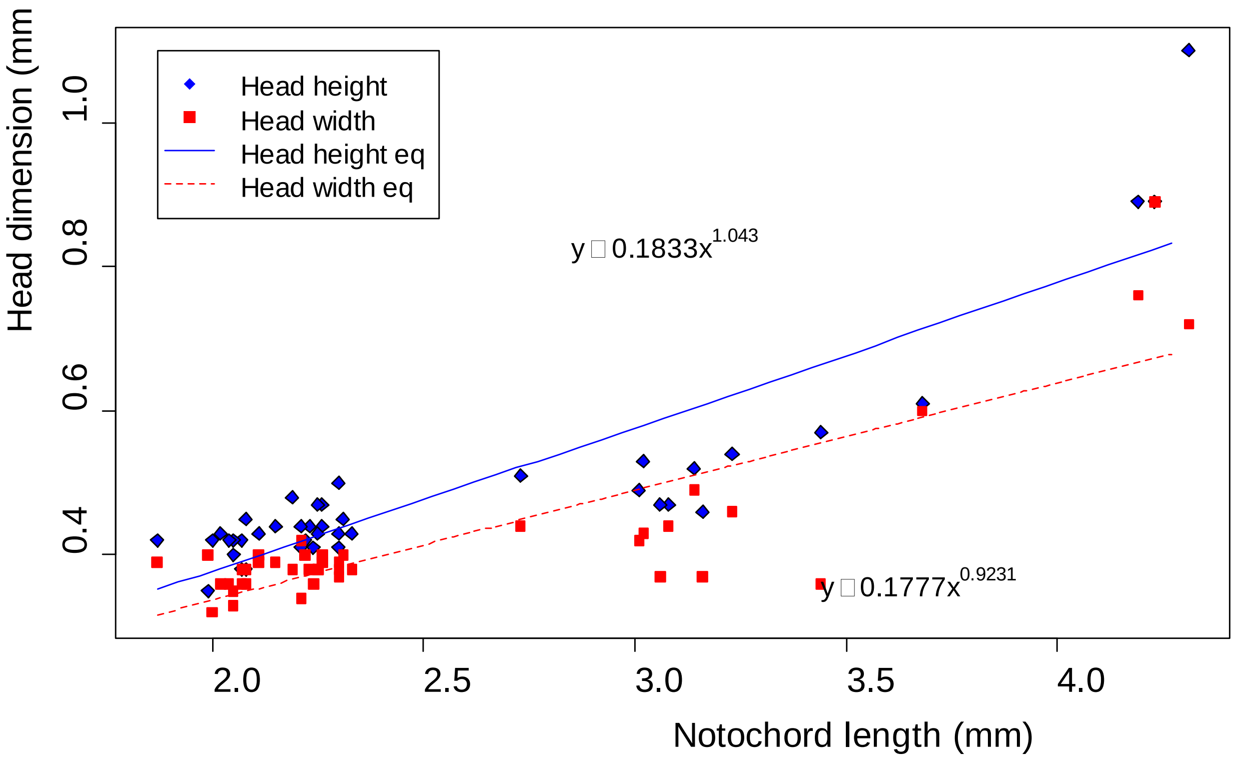

Figure 4-12 - Allometric regression plot for all lengths of combtooth blenny (*Hypsoblennius* spp.) larvae.

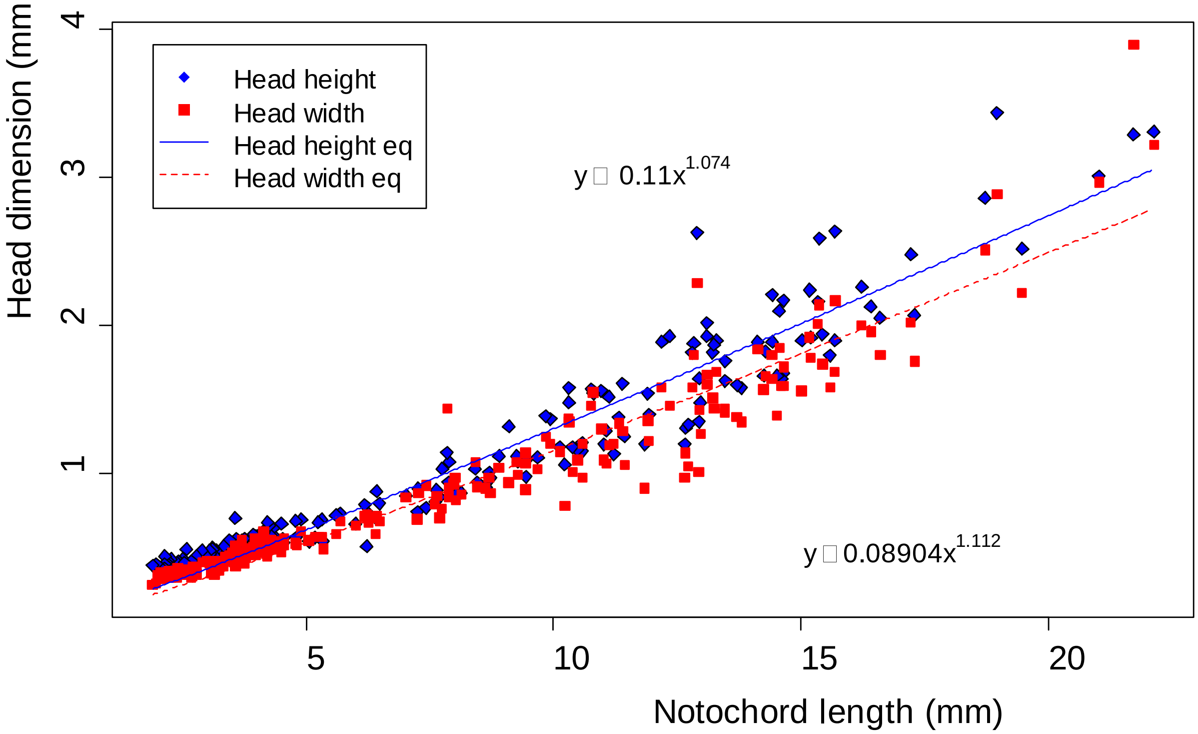

Figure 4-13 - Allometric regression plot for all lengths of goby (*Acanthogobius flavimanus, Lepidogobius lepidus* and CIQ goby complex [*Clevelandia, Ilypnus, Quietula*]) larvae.

Parameters of allometric regressions and their standard errors that described head capsule dimensions as a function of notochord length were used to predict the proportion of larvae for the five taxa that could be susceptible to entrainment through specific slot sizes of fine-mesh screens. The estimated average length-specific entrainment probabilities for the larval taxa as a function of slot dimension are presented in Tables 4-9 through 4-17. Tables of entrainment probabilities for anchovies less than and greater than 19 mm (0.75 in) (Tables 4-10 and 4-11), and silversides less than and greater than 15 mm (0.59 in) (Tables 4-13 and 4-14) follow the tables that present the results based on all the length data for those taxa. It should be noted that the results from the two models for the different size groups of anchovies and silversides are dissimilar at the inflection or transformation lengths due to the different allometric regressions for these taxa.

The probabilities in Tables 4-9 through 4-17 where used to assess the effects on population mortality when using a particular screen dimension for reducing the entrainment of larvae. As previously noted in this report, this approach requires the assumptions of linear growth and a constant rate of exponential natural mortality over the short time period that the larvae are vulnerable to entrainment. Using the tabulated probabilities the mortality reductions to the population by taxa were estimated across the length range of larvae potentially subject to entrainment. This was determined using data from studies that have been conducted throughout southern California to help account for any specific conditions that might have affected sampling during the studies at Harbor or Haynes. The summary of these data in Table 4-18 shows that the length ranges for anchovies and silversides collected from these studies roughly correspond to the length range presented in the entrainment probabilities shown in Tables 4-9 and 4-12, respectively. As a result, the probabilities from the allometric regressions of the two subsets of lengths will not be used. The range of lengths of the larvae collected for the other three taxa are considerably smaller. Therefore, the mortality reductions were calculated up to a maximum length of 10 mm (0.39 in.) for croakers and blennies, and up to a length of 15 mm (0.59 in.) for gobies. The population-level mortality reductions shown in Table 4-19 would apply to the total population where the larvae are at a length where they are no longer vulnerable to entrainment.

The actual percentage reductions in entrainment are less than the estimated reductions in population-level mortality since the reductions are applied directly to each length category and the totals do not account for the higher mortality associated with the smaller, early larval stages (Tables 4-20 through 4-24). The results indicate that the expected performance of fine-mesh screens in terms of numbers entrained (not considering population level effects) will vary considerably among species. Reductions in entrainment predicted based on head capsule were highest for silversides, which have the largest larvae of the fishes analyzed. Even at a mesh size of 1.0 mm (0.04 in.), the estimated reduction was almost 50%. The results indicate that there would be very little expected reductions for goby and blenny larvae. It is important to recognize that these estimates are based on head capsule dimensions and may not accurately reflect the actual entrainment reductions resulting from screens using these mesh sizes.

Table 4-9 - Estimated proportions (standard error in parentheses) of anchovy larvae entrained through four different size screen mesh openings based on head capsule allometric regressions on notochord lengths to 25 mm (0.98 in.).

Length (mm)	Square Mesh Opening			
	0.5 mm	0.75 mm	1.0 mm	2.0 mm
1	1 (0)	1 (0)	1 (0)	1 (0)
2	1 (0)	1 (0)	1 (0)	1 (0)
3	1 (0)	1 (0)	1 (0)	1 (0)
4	1 (0)	1 (0)	1 (0)	1 (0)
5	0.998 (0.005)	1 (0)	1 (0)	1 (0)
6	0.695 (0.214)	1 (0)	1 (0)	1 (0)
7	0.093 (0.083)	1.000 (0.000)	1 (0)	1 (0)
8	0.001 (0.002)	0.976 (0.025)	1 (0)	1 (0)
9	0 (0)	0.674 (0.151)	1 (0)	1 (0)
10	0 (0)	0.180 (0.100)	0.998 (0.003)	1 (0)
11	0 (0)	0.015 (0.013)	0.932 (0.046)	1 (0)
12	0 (0)	0.001 (0.001)	0.626 (0.127)	1 (0)
13	0 (0)	0 (0)	0.217 (0.091)	1 (0)
14	0 (0)	0 (0)	0.036 (0.022)	1 (0)
15	0 (0)	0 (0)	0.003 (0.002)	1 (0)
16	0 (0)	0 (0)	< 0.001	1.000 (0.000)
17	0 (0)	0 (0)	0 (0)	0.999 (0.001)
18	0 (0)	0 (0)	0 (0)	0.991 (0.004)
19	0 (0)	0 (0)	0 (0)	0.964 (0.013)
20	0 (0)	0 (0)	0 (0)	0.891 (0.030)
21	0 (0)	0 (0)	0 (0)	0.752 (0.049)
22	0 (0)	0 (0)	0 (0)	0.560 (0.061)
23	0 (0)	0 (0)	0 (0)	0.351 (0.056)
24	0 (0)	0 (0)	0 (0)	0.179 (0.040)
25	0 (0)	0 (0)	0 (0)	0.077 (0.021)

Table 4-10 - Estimated proportions (standard error in parentheses) of anchovy larvae entrained through four different size screen slot openings based on head capsule allometric regressions on notochord lengths less than or equal to 19 mm (0.75 in.).

Length (mm)	Square Mesh Opening			
	0.5 mm	0.75 mm	1.0 mm	2.0 mm
1	1 (0)	1 (0)	1 (0)	1 (0)
2	1 (0)	1 (0)	1 (0)	1 (0)
3	1 (0)	1 (0)	1 (0)	1 (0)
4	1.000 (0.000)	1 (0)	1 (0)	1 (0)
5	0.816 (0.192)	1 (0)	1 (0)	1 (0)
6	0.090 (0.102)	1 (0)	1 (0)	1 (0)
7	< 0.001	0.998 (0.003)	1 (0)	1 (0)
8	0 (0)	0.864 (0.107)	1 (0)	1 (0)
9	0 (0)	0.312 (0.152)	1 (0)	1 (0)
10	0 (0)	0.029 (0.025)	0.996 (0.004)	1 (0)
11	0 (0)	0.001 (0.001)	0.920 (0.053)	1 (0)
12	0 (0)	0 (0)	0.587 (0.131)	1 (0)
13	0 (0)	0 (0)	0.194 (0.083)	1 (0)
14	0 (0)	0 (0)	0.031 (0.020)	1 (0)
15	0 (0)	0 (0)	0.003 (0.002)	1 (0)
16	0 (0)	0 (0)	< 0.001	1 (0)
17	0 (0)	0 (0)	0 (0)	1 (0)
18	0 (0)	0 (0)	0 (0)	1 (0)
19	0 (0)	0 (0)	0 (0)	1 (0)

Table 4-11 - Estimated proportions (standard error in parentheses) of anchovy larvae entrained through four different size screen slot openings based on head capsule allometric regressions on notochord lengths greater than or equal to 19 mm (0.75 in.).

Length (mm)	Square Mesh Opening			
	0.5 mm	0.75 mm	1.0 mm	2.0 mm
19	< 0.001	0.006 (0.001)	0.043 (0.006)	0.671 (0.029)
20	< 0.001	0.004 (0.001)	0.026 (0.004)	0.571 (0.029)
21	< 0.001	0.002 (0.001)	0.016 (0.002)	0.477 (0.027)
22	< 0.001	0.001 (0.000)	0.010 (0.002)	0.388 (0.025)
23	< 0.001	0.001 (0.000)	0.007 (0.001)	0.310 (0.022)
24	0 (0)	0.001 (0.000)	0.004 (0.001)	0.243 (0.019)
25	0 (0)	< 0.001	0.003 (0.001)	0.189 (0.015)

Table 4-12 - Estimated proportions (standard error in parentheses) of silverside larvae entrained through four different size screen mesh openings based on head capsule allometric regressions on notochord lengths to 25 mm (0.98 in.).

Length (mm)	Square Mesh Opening			
	0.5 mm	0.75 mm	1.0 mm	2.0 mm
2	1 (0)	1 (0)	1 (0)	1 (0)
3	1 (0)	1 (0)	1 (0)	1 (0)
4	0.968 (0.069)	1 (0)	1 (0)	1 (0)
5	0.115 (0.176)	1 (0)	1 (0)	1 (0)
6	0 (0)	0.969 (0.053)	1 (0)	1 (0)
7	0 (0)	0.256 (0.250)	1 (0)	1 (0)
8	0 (0)	< 0.001	0.941 (0.079)	1 (0)
9	0 (0)	0 (0)	0.262 (0.215)	1 (0)
10	0 (0)	0 (0)	0.002 (0.003)	1 (0)
11	0 (0)	0 (0)	0 (0)	1 (0)
12	0 (0)	0 (0)	0 (0)	1 (0)
13	0 (0)	0 (0)	0 (0)	0.997 (0.003)
14	0 (0)	0 (0)	0 (0)	0.938 (0.041)
15	0 (0)	0 (0)	0 (0)	0.679 (0.109)
16	0 (0)	0 (0)	0 (0)	0.282 (0.104)
17	0 (0)	0 (0)	0 (0)	0.050 (0.033)
18	0 (0)	0 (0)	0 (0)	0.003 (0.003)
19	0 (0)	0 (0)	0 (0)	< 0.001
20	0 (0)	0 (0)	0 (0)	0 (0)
21	0 (0)	0 (0)	0 (0)	0 (0)
22	0 (0)	0 (0)	0 (0)	0 (0)
23	0 (0)	0 (0)	0 (0)	0 (0)
24	0 (0)	0 (0)	0 (0)	0 (0)
25	0 (0)	0 (0)	0 (0)	0 (0)

Table 4-13 - Estimated proportions (standard error in parentheses) of silverside larvae entrained through four different size screen slot openings based on head capsule allometric regressions on notochord lengths less than or equal to 15 mm (0.59 in.).

Length (mm)	Square Mesh Opening			
	0.5 mm	0.75 mm	1.0 mm	2.0 mm
2	1 (0)	1 (0)	1 (0)	1 (0)
3	1.000 (0.000)	1 (0)	1 (0)	1 (0)
4	0.679 (0.281)	1 (0)	1 (0)	1 (0)
5	0.026 (0.040)	0.999 (0.002)	1 (0)	1 (0)
6	0 (0)	0.815 (0.159)	1 (0)	1 (0)
7	0 (0)	0.165 (0.135)	0.998 (0.004)	1 (0)
8	0 (0)	0.002 (0.003)	0.872 (0.099)	1 (0)
9	0 (0)	0 (0)	0.333 (0.164)	1 (0)
10	0 (0)	0 (0)	0.031 (0.028)	1 (0)
11	0 (0)	0 (0)	0.001 (0.001)	1 (0)
12	0 (0)	0 (0)	0 (0)	1 (0)
13	0 (0)	0 (0)	0 (0)	1.000 (0.000)
14	0 (0)	0 (0)	0 (0)	0.995 (0.003)
15	0 (0)	0 (0)	0 (0)	0.962 (0.019)

Table 4-14 - Estimated proportions (standard error in parentheses) of silverside larvae entrained through for different size screen slot openings based on head capsule allometric regressions on notochord lengths greater than or equal to 15 mm (0.59 in.).

Length (mm)	Square Mesh Opening			
	0.5 mm	0.75 mm	1.0 mm	2.0 mm
15	1 (0)	1 (0)	1 (0)	1 (0)
16	1.000 (0.000)	1 (0)	1 (0)	1 (0)
17	0.679 (0.281)	1 (0)	1 (0)	1 (0)
18	0.026 (0.040)	0.999 (0.002)	1 (0)	1 (0)
19	0 (0)	0.815 (0.159)	1 (0)	1 (0)
20	0 (0)	0.165 (0.135)	0.998 (0.004)	1 (0)
21	0 (0)	0.002 (0.003)	0.872 (0.099)	1 (0)
22	0 (0)	0 (0)	0.333 (0.164)	1 (0)
23	0 (0)	0 (0)	0.031 (0.028)	1 (0)
24	0 (0)	0 (0)	0.001 (0.001)	1 (0)
25	0 (0)	0 (0)	0 (0)	1 (0)

Table 4-15 - Estimated proportions (standard error in parentheses) of croaker larvae entrained through four different size screen mesh openings based on head capsule allometric regressions on notochord lengths to 20 mm (0.79 in.).

Length (mm)	Square Mesh Opening			
	0.5 mm	0.75 mm	1.0 mm	2.0 mm
1	1 (0)	1 (0)	1 (0)	1 (0)
2	0.706 (0.367)	1 (0)	1 (0)	1 (0)
3	0.001 (0.003)	0.689 (0.332)	1.000 (0.000)	1 (0)
4	0 (0)	0.010 (0.019)	0.652 (0.297)	1 (0)
5	0 (0)	0 (0)	0.020 (0.030)	1 (0)
6	0 (0)	0 (0)	0 (0)	0.999 (0.001)
7	0 (0)	0 (0)	0 (0)	0.904 (0.085)
8	0 (0)	0 (0)	0 (0)	0.392 (0.168)
9	0 (0)	0 (0)	0 (0)	0.052 (0.038)
10	0 (0)	0 (0)	0 (0)	0.002 (0.002)
11	0 (0)	0 (0)	0 (0)	0 (0)
12	0 (0)	0 (0)	0 (0)	0 (0)
13	0 (0)	0 (0)	0 (0)	0 (0)
14	0 (0)	0 (0)	0 (0)	0 (0)
15	0 (0)	0 (0)	0 (0)	0 (0)
16	0 (0)	0 (0)	0 (0)	0 (0)
17	0 (0)	0 (0)	0 (0)	0 (0)
18	0 (0)	0 (0)	0 (0)	0 (0)
19	0 (0)	0 (0)	0 (0)	0 (0)
20	0 (0)	0 (0)	0 (0)	0 (0)

Table 4-16 - Estimated proportions (standard error in parentheses) of combtooth blenny larvae entrained through four different size screen mesh openings based on head capsule allometric regressions on notochord lengths to 20 mm (0.79 in.).

Length (mm)	Square Mesh Opening			
	0.5 mm	0.75 mm	1.0 mm	2.0 mm
2	0.938 (0.099)	1 (0)	1 (0)	1 (0)
3	0.164 (0.184)	0.948 (0.065)	1.000 (0.000)	1 (0)
4	0.000 (0.001)	0.384 (0.202)	0.938 (0.060)	1 (0)
5	0 (0)	0.031 (0.026)	0.523 (0.163)	1 (0)
6	0 (0)	0.001 (0.001)	0.123 (0.064)	0.999 (0.002)
7	0 (0)	0 (0)	0.016 (0.010)	0.975 (0.015)
8	0 (0)	0 (0)	0.002 (0.001)	0.873 (0.046)
9	0 (0)	0 (0)	< 0.001	0.670 (0.068)
10	0 (0)	0 (0)	0 (0)	0.443 (0.065)
11	0 (0)	0 (0)	0 (0)	0.254 (0.044)
12	0 (0)	0 (0)	0 (0)	0.134 (0.027)
13	0 (0)	0 (0)	0 (0)	0.065 (0.014)
14	0 (0)	0 (0)	0 (0)	0.031 (0.007)
15	0 (0)	0 (0)	0 (0)	0.014 (0.003)
16	0 (0)	0 (0)	0 (0)	0.006 (0.002)
17	0 (0)	0 (0)	0 (0)	0.003 (0.001)
18	0 (0)	0 (0)	0 (0)	0.001 (0.000)
19	0 (0)	0 (0)	0 (0)	0.001 (0.000)
20	0 (0)	0 (0)	0 (0)	< 0.001

Table 4-17 - Estimated proportions (standard error in parentheses) of goby larvae entrained through four different size screen mesh openings based on head capsule allometric regressions on notochord lengths to 25 mm (0.98 in.).

Length (mm)	Square Mesh Opening			
	0.5 mm	0.75 mm	1.0 mm	2.0 mm
1	1 (0)	1 (0)	1 (0)	1 (0)
2	1 (0)	1 (0)	1 (0)	1 (0)
3	1.000 (0.001)	1 (0)	1 (0)	1 (0)
4	0.586 (0.308)	1 (0)	1 (0)	1 (0)
5	0.011 (0.019)	0.976 (0.034)	1 (0)	1 (0)
6	0 (0)	0.481 (0.246)	0.999 (0.001)	1 (0)
7	0 (0)	0.024 (0.028)	0.894 (0.091)	1 (0)
8	0 (0)	0.000 (0.000)	0.359 (0.175)	1 (0)
9	0 (0)	0 (0)	0.030 (0.027)	1 (0)
10	0 (0)	0 (0)	0.001 (0.001)	1 (0)
11	0 (0)	0 (0)	0 (0)	1.000 (0.000)
12	0 (0)	0 (0)	0 (0)	0.993 (0.005)
13	0 (0)	0 (0)	0 (0)	0.935 (0.035)
14	0 (0)	0 (0)	0 (0)	0.722 (0.087)
15	0 (0)	0 (0)	0 (0)	0.398 (0.093)
16	0 (0)	0 (0)	0 (0)	0.141 (0.050)
17	0 (0)	0 (0)	0 (0)	0.035 (0.016)
18	0 (0)	0 (0)	0 (0)	0.005 (0.003)
19	0 (0)	0 (0)	0 (0)	0.001 (0.000)
20	0 (0)	0 (0)	0 (0)	0.000 (0.000)
21	0 (0)	0 (0)	0 (0)	0 (0)
22	0 (0)	0 (0)	0 (0)	0 (0)
23	0 (0)	0 (0)	0 (0)	0 (0)
24	0 (0)	0 (0)	0 (0)	0 (0)
25	0 (0)	0 (0)	0 (0)	0 (0)

Table 4-18 - Summary statistics on lengths (mm) of larvae from five taxa measured from power plant studies in southern California (Table 3-2) that were used in estimating the size frequency distribution of larvae potentially subject to entrainment.

Taxa	N	Min	Max	Median	Mean	Standard Deviation	99th Percentile
anchovies	2427	1.1	31.3	9.6	10.0	6.91	27.7
silversides	1933	2.5	24.4	8.5	9.1	2.66	17.6
croakers	2240	0.9	14.0	2.4	2.9	1.51	7.9
blennies	3269	1.6	13.1	2.3	2.4	0.47	3.6
gobies	1610	1.8	27.1	4.3	4.6	2.08	12.4

Table 4-19 - Estimated percentage reductions (two standard errors in parentheses) in mortality (relative to an open intake) to the population surviving past the size where they would be subject to entrainment, based on probabilities of screen entrainment for larvae from 5 taxonomic categories of fishes for four square mesh openings.

Taxa	Length Range (mm)	0.5 mm Mesh	0.75 mm Mesh	1.0 mm Mesh	2.0 mm Mesh
anchovies	2 – 25	76.9 (2.4)	64.6 (2.3)	52.8 (2.3)	12.9 (2.2)
silversides	2 – 25	87.2 (2.0)	78.2 (2.5)	70.0 (2.5)	41.9 (2.4)
croakers	1 – 10	82.9 (7.4)	73.0 (7.0)	63.3 (6.6)	26.5 (5.9)
blennies	1 – 10	87.8 (6.3)	73.7 (6.5)	60.0 (6.7)	11.6 (4.3)
gobies	1 – 15	76.0 (4.4)	63.5 (4.1)	51.4 (3.9)	6.3 (2.9)

Table 4-20 - Estimated reductions in entrainment for anchovy larvae through four different size screen mesh openings based on a theoretical entrainment of 100 million larvae and the estimated probability of entrainment for each length category based on head capsule dimensions.

Length (mm)	Count	Percent of Total	Total Entrainment	Entrainment 0.5 mm	Entrainment 0.75 mm	Entrainment 1.0 mm	Entrainment 2.0 mm
1	6	0.25	253,378	253,378	253,378	253,378	253,378
2	285	12.04	12,035,473	12,035,473	12,035,473	12,035,473	12,035,473
3	440	18.58	18,581,081	18,581,081	18,581,081	18,581,081	18,581,081
4	108	4.56	4,560,811	4,560,811	4,560,811	4,560,811	4,560,811
5	69	2.91	2,913,851	2,906,567	2,913,851	2,913,851	2,913,851
6	35	1.48	1,478,041	1,026,647	1,478,041	1,478,041	1,478,041
7	58	2.45	2,449,324	227,297	2,449,079	2,449,324	2,449,324
8	98	4.14	4,138,514	4,966	4,039,189	4,138,514	4,138,514
9	101	4.27	4,265,203	0	2,875,600	4,265,203	4,265,203
10	114	4.81	4,814,189	0	867,998	4,802,154	4,814,189
11	118	4.98	4,983,108	0	76,740	4,643,758	4,983,108
12	122	5.15	5,152,027	0	2,576	3,226,199	5,152,027
13	114	4.81	4,814,189	0	0	1,045,160	4,814,189
14	104	4.39	4,391,892	0	0	156,351	4,391,892
15	85	3.59	3,589,527	0	0	11,128	3,589,527
16	108	4.56	4,560,811	0	0	456	4,560,355
17	89	3.76	3,758,446	0	0	0	3,753,560
18	71	3.00	2,998,311	0	0	0	2,971,926
19	57	2.41	2,407,095	0	0	0	2,319,236
20	46	1.94	1,942,568	0	0	0	1,731,022
21	42	1.77	1,773,649	0	0	0	1,334,139
22	40	1.69	1,689,189	0	0	0	946,453
23	22	0.93	929,054	0	0	0	325,726
24	15	0.63	633,446	0	0	0	113,260
25	21	0.89	886,824	0	0	0	67,842
Totals	2,368	100.00	100,000,000	39,596,220	50,133,818	64,560,883	96,544,126
Percentage Reduction				**60.40**	**49.87**	**35.44**	**3.46**

Table 4-21 - Estimated reductions in entrainment for silverside larvae through four different size screen mesh openings based on a theoretical entrainment of 100 million larvae and the estimated probability of entrainment for each length category based on head capsule dimensions.

Length (mm)	Count	Percent of Total	Total Entrainment	Entrainment 0.5 mm	Entrainment 0.75 mm	Entrainment 1.0 mm	Entrainment 2.0 mm
2	0	0.00	0	0	0	0	0
3	6	0.31	310,398	310,398	310,398	310,398	310,398
4	13	0.67	672,530	650,673	672,530	672,530	672,530
5	52	2.69	2,690,119	309,902	2,690,119	2,690,119	2,690,119
6	157	8.12	8,122,090	0	7,870,305	8,122,090	8,122,090
7	274	14.17	14,174,858	0	3,627,346	14,174,858	14,174,858
8	464	24.00	24,004,139	0	4,801	22,590,295	24,004,139
9	335	17.33	17,330,574	0	0	4,537,144	17,330,574
10	175	9.05	9,053,285	0	0	17,201	9,053,285
11	128	6.62	6,621,831	0	0	0	6,621,831
12	106	5.48	5,483,704	0	0	0	5,483,704
13	91	4.71	4,707,708	0	0	0	4,691,231
14	49	2.53	2,534,920	0	0	0	2,378,515
15	35	1.81	1,810,657	0	0	0	1,229,798
16	19	0.98	982,928	0	0	0	277,382
17	9	0.47	465,598	0	0	0	23,420
18	6	0.31	310,398	0	0	0	931
19	5	0.26	258,665	0	0	0	26
20	2	0.10	103,466	0	0	0	0
21	3	0.16	155,199	0	0	0	0
22	0	0.00	0	0	0	0	0
23	1	0.05	51,733	0	0	0	0
24	3	0.16	155,199	0	0	0	0
25	0	0.00	0	0	0	0	0
Totals	1,933	100.00	100,000,000	1,270,973	15,175,499	53,114,635	97,064,832
Percentage Reduction				**98.73**	**84.82**	**46.89**	**2.94**

Table 4-22 - Estimated reductions in entrainment for croaker larvae through four different size screen mesh openings based on a theoretical entrainment of 100 million larvae and the estimated probability of entrainment for each length category based on head capsule dimensions.

Length (mm)	Count	Percent of Total	Total Entrainment	Entrainment 0.5 mm	Entrainment 0.75 mm	Entrainment 1.0 mm	Entrainment 2.0 mm
1	150	6.71	6,711,409	6,711,409	6,711,409	6,711,409	6,711,409
2	1,100	49.22	49,217,002	34,757,047	49,217,002	49,217,002	49,217,002
3	491	21.97	21,968,680	26,362	15,127,633	21,964,286	21,968,680
4	201	8.99	8,993,289	0	91,732	5,866,322	8,993,289
5	118	5.28	5,279,642	0	0	107,177	5,279,642
6	96	4.30	4,295,302	0	0	0	4,292,725
7	47	2.10	2,102,908	0	0	0	1,900,819
8	23	1.03	1,029,083	0	0	0	402,989
9	7	0.31	313,199	0	0	0	16,349
10	2	0.09	89,485	0	0	0	197
Totals	2,235	100.00	100,000,000	41,494,819	71,147,776	83,866,197	98,783,101
			Percentage Reduction	**58.51**	**28.85**	**16.13**	**1.22**

Table 4-23 - Estimated reductions in entrainment for blenny larvae through four different size screen mesh openings based on a theoretical entrainment of 100 million larvae and the estimated probability of entrainment for each length category based on head capsule dimensions.

Length (mm)	Count	Percent of Total	Total Entrainment	Entrainment 0.5 mm	Entrainment 0.75 mm	Entrainment 1.0 mm	Entrainment 2.0 mm
1	2,470	75.63	75,627,679	70,953,889	75,627,679	75,627,679	75,627,679
2	756	23.15	23,147,581	3,784,630	21,946,222	23,145,266	23,147,581
3	34	1.04	1,041,029	416	399,547	976,797	1,041,029
4	5	0.15	153,092	0	4,715	80,037	153,092
5	1	0.03	30,618	0	28	3,763	30,573
6	0	0.00	0	0	0	0	0
7	0	0.00	0	0	0	0	0
8	0	0.00	0	0	0	0	0
9	0	0.00	0	0	0	0	0
10	3,266	100.00	100,000,000	74,738,934	97,978,190	99,833,543	99,999,954
Totals	2,470	75.63	75,627,679	70,953,889	75,627,679	75,627,679	75,627,679
			Percentage Reduction	**25.26**	**2.02**	**0.17**	**0.00**

Table 4-24 - Estimated reductions in entrainment for goby larvae through four different size screen mesh openings based on a theoretical entrainment of 100 million larvae and the estimated probability of entrainment for each length category based on head capsule dimensions.

Length (mm)	Count	Percent of Total	Total Entrainment	Entrainment 0.5 mm	Entrainment 0.75 mm	Entrainment 1.0 mm	Entrainment 2.0 mm
2	56	3.49	3,489,097	3,489,097	3,489,097	3,489,097	3,489,097
3	423	26.36	26,355,140	26,355,140	26,355,140	26,355,140	26,355,140
4	472	29.41	29,408,100	29,393,396	29,408,100	29,408,100	29,408,100
5	424	26.42	26,417,445	15,467,414	26,417,445	26,417,445	26,417,445
6	92	5.73	5,732,087	64,773	5,596,237	5,732,087	5,732,087
7	35	2.18	2,180,685	0	1,047,819	2,178,941	2,180,685
8	23	1.43	1,433,022	0	34,393	1,281,551	1,433,022
9	21	1.31	1,308,411	0	131	470,112	1,308,411
10	22	1.37	1,370,717	0	0	40,436	1,370,717
11	21	1.31	1,308,411	0	0	654	1,308,411
12	5	0.31	311,526	0	0	0	311,464
13	6	0.37	373,832	0	0	0	371,364
14	3	0.19	186,916	0	0	0	174,748
15	2	0.12	124,611	0	0	0	89,956
Totals	1,605	100.00	100,000,000	74,769,819	92,348,361	95,373,564	99,950,648
			Percentage Reduction	**25.23**	**7.65**	**4.63**	**0.05**

4.2.2 Estimate of Survival off Fine-mesh Screens

Survival of eggs, larvae, and early juveniles that would be retained on the fine-mesh screens is dependent upon their biology (species, life stage, relative hardiness), the screen operating characteristics (rotation speed, spraywash pressure, etc.), and local hydraulic conditions.

That said, poor survival of post-impinged larval fish has been observed in the laboratory with fine-mesh traveling screens (EPRI 2012). That study tested survival rates on a number of species that have been shown to be moderately tolerant to the effects of impingement for a variety of modified traveling water screens types that included modified-Ristroph, Geiger, Hydrolox and Beaudrey. The general results of the study showed a consistent pattern for all species tested. In particular, survival was lowest for fishes smaller than about 12 mm (0.47 in.). For the fish less than 12 mm collected off of the test screens, survival was less than 30% regardless of screen type or approach velocity. By comparison, control fishes (i.e., not exposed to the screens) smaller than 12 mm (0.47 in.) had survival rates of about 73%. Poor survival likely results from the fact that at this stage in their development, larvae are extremely sensitive to the impingement, collection and transfer process. By contrast, fishes greater than about 12 mm (0.47 in.) exhibited high survival (approximately 90%). This survival increase appears to be associated with the development of scales and musculature by the organisms. While there was some variation in length among the test organisms as to when this musculature and scales develop, it was generally around 12.0 mm (0.47 in.) for the species tested. - A cursory review of scale-drawings[1] indicates that west coast gobies and blennies mature at smaller total lengths than the fish species tested in EPRI (2010). Therefore, the length at which higher survival becomes evident may be shorter for west-coast blennies and gobies than the freshwater species tested in the laboratory.

4.2.3 Estimate of Overall Performance

The survival estimates in Table 4-25 were applied to the lengths in Tables 4-20 through 4-24 that corresponded to larvae between flexion and transformation (Table 4-25). All of the combtooth blenny larvae collected from the studies were smaller than the estimated length at flexion of 7 mm (0.28 in.) (Table 4-23). The estimates lengths at transformation for the other four taxa were greater than the lengths entrained in Tables 4-20 through 4-24, so the survival estimates were extrapolated over the length from flexion through the largest length collected. Using the same entrainment numbers provided in Tables 4-20 through 4-24, the combined estimated survival due to screen exclusion and following impingement, screenwash, and transfer are provided in Tables 4-26 through 4-29. Due to the small size of the larvae collected, the overall expected survival is 1% or less for all four taxa and all four mesh sizes. The survival would be zero for combtooth blennies due to the small size of the larvae entrained.

Table 4-25 - Estimated lengths (mm) of flexion and transformation for the five target taxa. Estimates derived from information in Moser (1996).

Taxon	Length at Flexion (mm [in.])	Length at Transformation (mm [in.])
Anchovies	12 (0.47)	>30 (1.28)
Silversides	11 (0.43)	21 (0.83)
Croakers	7 (0.28)	17 (0.67)
Blennies	7 (0.28)	18 (0.71)
Gobies	8 (0.31)	15 (0.59)

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[1] Scale drawings were taken from Moser 1996; Miller et al. 1979;

Table 4-26 - Estimated survival for post-flexion northern anchovy larvae based on data in Table 4-20 assuming entrainment of 100 million larvae and post impingement survival of 1%.

Length	Total Estimated Survival 0.5 mm	Total Estimated Survival 0.75 mm	Total Estimated Survival 1.0 mm	Total Estimated Survival 2.0 mm
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	51,520	51,495	19,258	0
13	48,142	48,142	37,690	0
14	43,919	43,919	42,355	0
15	35,895	35,895	35,784	0
16	45,608	45,608	45,604	5
17	37,584	37,584	37,584	49
18	29,983	29,983	29,983	264
19	24,071	24,071	24,071	879
20	19,426	19,426	19,426	2,115
21	17,736	17,736	17,736	4,395
22	16,892	16,892	16,892	7,427
23	9,291	9,291	9,291	6,033
24	6,334	6,334	6,334	5,202
25	8,868	8,868	8,868	8,190
Totals	**395,270**	**395,245**	**350,877**	**34,559**
% Survival	**0.40**	**0.40**	**0.35**	**0.03**

Table 4-27 - Estimated survival for post-flexion silverside larvae based on data in Table 4-21 assuming entrainment of 100 million larvae and post impingement survival of 5%.

Length	Total Estimated Survival 0.5 mm	Total Estimated Survival 0.75 mm	Total Estimated Survival 1.0 mm	Total Estimated Survival 2.0 mm
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	331,092	331,092	331,092	0
12	274,185	274,185	274,185	0
13	235,385	235,385	235,385	824
14	126,746	126,746	126,746	7,820
15	90,533	90,533	90,533	29,043
16	49,146	49,146	49,146	35,277
17	23,280	23,280	23,280	22,109
18	15,520	15,520	15,520	15,473
19	12,933	12,933	12,933	12,932
20	5,173	5,173	5,173	5,173
21	7,760	7,760	7,760	7,760
22	0	0	0	0
23	2,587	2,587	2,587	2,587
24	7,760	7,760	7,760	7,760
25	0	0	0	0
Totals	**1,182,100**	**1,182,100**	**1,182,100**	**146,758**
% Survival	**1.18**	**1.18**	**1.18**	**0.15**

Table 4-28 - Estimated survival for post-flexion croaker larvae based on data in Table 4-22 assuming entrainment of 100 million larvae and post impingement survival of 20%.

Length	Total Estimated Survival 0.5 mm	Total Estimated Survival 0.75 mm	Total Estimated Survival 1.0 mm	Total Estimated Survival 2.0 mm
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	420,582	420,582	420,582	40,418
8	205,817	205,817	205,817	125,219
9	62,640	62,640	62,640	59,370
10	17,897	17,897	17,897	17,858
Totals	**706,935**	**706,935**	**706,935**	**242,864**
% Survival	**0.71**	**0.71**	**0.71**	**0.24**

Table 4-29 - Estimated survival for post-flexion goby larvae based on data in Table 4-24 assuming entrainment of 100 million larvae and post impingement survival of 1.0%.

Length	Total Estimated Survival 0.5 mm	Total Estimated Survival 0.75 mm	Total Estimated Survival 1.0 mm	Total Estimated Survival 2.0 mm
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	214,953	209,794	22,721	0
9	196,262	196,242	125,745	0
10	205,607	205,607	199,542	0
11	196,262	196,262	196,164	0
12	46,729	46,729	46,729	9
13	56,075	56,075	56,075	370
14	28,037	28,037	28,037	1,825
15	18,692	18,692	18,692	5,198
Totals	**962,617**	**957,438**	**693,704**	**7,403**
% Survival	**0.96**	**0.96**	**0.69**	**0.01**

5
DISCUSSION

The results of the analysis presented in Chapter 4 are discussed in terms of both exclusion for cylindrical wedgewire screens and retention and survival mortality for fine-mesh modified traveling water screens. This discussion is followed by the implication of biological performance for Harbor and Haynes considering the engineering analysis presented in Chapter 2. The potential for interim use of technologies that focus only on impingeable life stages for both Harbor and Haynes is also covered.

5.1 Overall Biological Performance for Species of Concern

Based on entrainment sampling results, the four species of concern were identified for Harbor included anchovies, croaker, goby and blennies. These same species of concern were selected for Haynes along with one additional species, silversides. The species of concern comprised 95.7% of the entrainment at Harbor and 98% of the entrainment at Haynes. The results of the analysis of biological performance of either modified fine-mesh traveling water screens or narrow-slot cylindrical wedgewire screens varied for the four mesh/slot sizes tested (i.e., 0.5 mm, 0.75 mm, 1.0 mm and 2.0 mm). The results for the retention (applicable to fine-mesh screens) and exclusion (applicable to narrow-slot wedgewire) are shown in Table 5-1.

Retention/exclusion ranged from 99% down to 25.3% for blennies for the smallest mesh sized tested (0.5 mm). For a 2.0 mm mesh size retention/exclusion was less than 4% for all four species. For a 1.0 mm mesh/slot size retention/exclusion is estimated to be less than 50% for all species and less than 1% for blennies (blennies make up over 20% of the entrainment at Haynes). Goby are the dominant species entrained at both facilities making up over 77.5% of the entrainment at Harbor and almost 52% of the entrainment at Haynes. At the smallest mesh size of 0.5 mm goby retention/exclusion is just over 25%. Retention/exclusion for croaker, a recreationally important species, range from 58.5% for a 0.5 mm mesh to a little over 1% for a 2 mm mesh size.

Table 5-1 – Estimated retention on fine-mesh screens and exclusion for narrow-slot wedgewire screens for the four species of concern for the Harbor and Haynes Generating Station.

Species	Entrainment (%) with 0.5 mm mesh/slot size	Entrainment (%) with 0.75 mm mesh/slot size	Entrainment (%) with 1.0 mm mesh/slot size	Entrainment (%) with 2.0 mm mesh/slot size
bay anchovy	60.4	49.87	35.44	3.46
silversides	98.73	84.82	46.89	2.94
croaker	58.51	28.85	16.13	1.22
goby	25.23	7.65	4.63	0.05
blenny	25.26	2.02	0.17	0

Overall performance for each facility was calculated by multiplying the fraction excluded for each mesh size by the percent entrainment of all five species of concern and the results are shown in Table 5-2 for Harbor and 5-3 for Haynes. For Harbor the overall retention/exclusion for the species of concern ranged from just under 30% at 0.5 mm to less than 1% for a 2 mm mesh/slot size. Most of the exclusion at 0.5 mm is from gobies (19.6%) and croaker (8.2%). For Haynes overall retention/exclusion for the species of concern ranged from 43.5% for a 0.5 mm mesh/slot size to less than 1% for a 2 mm mesh/slot size. Silversides and gobies made up the bulk of the retention/exclusion at 23.6% and 13% respectively.

Table 5-2 – The estimated retention on fine-mesh modified traveling water screens or exclusion for narrow-slot cylindrical wedgewire screens for species of concern as a fraction of the total entrainment for all species of concern for the Harbor Generating Station

Harbor Retention/Exclusion as a Function of Total Entrainment					
Species	Percent of Total Entrainment	Fraction of Species of Concern Retained or Excluded at 0.5 mm	Fraction of Species of Concern Retained or Excluded at 0.75 mm	Fraction of Species of Concern Retained or Excluded at 1.0 mm	Fraction of Species of Concern Retained or Excluded at 2.0 mm
northern anchovy	1.33	0.8	0.4	0.47	0.05
croaker	13.97	8.17	4.03	2.25	0.17
blenny	2.83	0.71	0.06	0.004	0
goby	77.85	19.64	5.96	3.6	0.04
Total	95.98	29.32	10.45	6.324	0.26

Table 5-3 - The estimated retention on fine-mesh modified traveling water screens or exclusion for narrow-slot cylindrical wedgewire screens for species of concern as a fraction of the total entrainment for all species of concern for the Haynes Generating Station

Haynes Retention/Exclusion as a Function of Total Entrainment					
Species	**Percent of Total Entrainment**	**Fraction of Species of Concern Retained or Excluded**	**Fraction of Species of Concern Retained or Excluded**	**Fraction of Species of Concern Retained or Excluded**	**Fraction of Species of Concern Retained or Excluded**
northern anchovy	0.6	0.36	0.3	0.21	0.02
silversides	23.94	23.6	20.31	11.01	0.7
croaker	2.33	1.36	0.67	0.38	0.03
blenny	20.49	5.18	0.41	0.03	0
goby	51.44	12.98	3.94	2.38	0.03
Total	98.8	43.48	25.63	14.01	0.78

For fine-mesh modified traveling water screens there is additional mortality imparted as a result of the collection process and the overall entrainment survival estimated for the species of concern are shown in Table 5-4. While the smaller 0.5 mm and 0.75 mm screens retain more larvae (see Tables 5-2 and 5-3), those smaller larvae have not yet developed scales and musculature sufficient to survive the impingement and contact on the screens involved in the collection process. The estimated survival rates for each species of concern was less than 1% with goby having the highest survival rate of 0.96% and blenny having the lowest at 0%. The result is that survival of retained larvae is estimated to be approximately 2.25% or less regardless of the screen mesh size used.

Table 5-4 – Expected fine-mesh modified traveling water screen performance based on expected entrainment survival

Overall Biological Performance (Retention + Survival) for Fine-mesh Screens				
Species	**Entrainment Survival (%) with 0.5 mm mesh/slot size**	**Entrainment Survival (%) with 0.75 mm mesh/slot size**	**Entrainment Survival (%) with 1.0 mm mesh/slot size**	**Entrainment Survival (%) with 2.0 mm mesh/slot size**
northern anchovy	0.4	0.4	0.35	0.03
silversides	0.18	0.18	0.18	0.15
croaker	0.71	0.71	0.71	0.24
goby	0.96	0.96	0.69	0.01
blenny	0	0	0	0
Total	2.25	2.25	1.93	0.43

5.2 Implications of Retention/Exclusion Analysis for Harbor and Haynes

This section discusses the overall feasibility of the two entrainment reduction technologies evaluated for Harbor and Haynes. The discussion is based on the morphology of the head capsule for larvae from the species of concern used to estimate retention on modified traveling water screens and exclusion for narrow-slot cylindrical wedgewire screens. In addition, the survival of the species of concern life stages was estimated for fine-mesh modified traveling water screens using laboratory studies. Uncertainties are discussed relative to the analytical methods, as well as the results of the engineering analysis discussed in Chapter 2.

5.2.1 Harbor

The use of the head capsule analysis conducted was specifically designed to estimate retention of entrainable life stages for a square mesh. Narrow-slot wedgewire screens have a single slot that extends over the entire length of the screen module and therefore depending on the angle of the larval head capsule contacting the slot, it is possible that some larvae that would be excluded by a square mesh would be able to pass through the slot. This method therefore may over estimate the amount of exclusion actually achieved for cylindrical wedgewire screens. This is somewhat offset by the fact that there is evidence that sweeping flow can enhance organism bypass of screen modules beyond that based on exclusion alone. However, the available hydraulic information for Harbor suggests there is little ambient current in the area of the Los Angeles Harbor complex where the screens would be located. This would be especially true during periods when tidal currents are very low. The estimated exclusion of 25.3% of the larvae for narrow-slot cylindrical wedgewire screens does also not take into account the uncertainty regarding potential re-impingement on the screens which is also an issue in the low flow environment at the Harbor intake. Since Harbor's cooling water flow exceeds that of local ambient current flow, larvae that enter Harbors hydraulic zone of influence are potentially subject to re-entrainment. Additionally, the current use of Slip 5 for ship docking would make it highly problematic to secure the necessary permissions and permits necessary for construction. The result is that use of 0.5 mm cylindrical wedgewire screens for an estimated cost of approximately $7 million would reduce entrainment by less than 25% and be subject to additional risk of re-impingement on the screens. Almost 96% of the reduction would be for three forage species that include goby (51.4%), silversides (23.9%) and blenny (20.5%). The expected biological performance of fine-mesh modified traveling water screens based on estimated exclusion and survival would be less than 2.5% for an estimated cost of approximately $3.9 million. The technology cost estimates are based on preliminary conceptual designs with a confidence interval of ±50%.

5.2.2 Haynes

The same uncertainties regarding the head capsule width analysis discussed for Harbor also apply to Haynes, such that estimated larval exclusion of 43.5% is likely to be an over estimate for the expected entrainment reductions from a wedgewire screen. As discussed in Chapter 2 there are significant issues relative to installing cylindrical wedgewire at this facility. Installing narrow-slot wedgewire screens offshore is not considered practical given it would require an intake conduit 1.8 miles long to reach the Pacific Ocean and then another mile or more offshore with sufficient depth for the screens to withstand hydraulic forces during storm events. Further, construction of such a tunnel would affect navigation in the marina and biofouling control would be highly problematic due to the offshore location. The only practical alternative for narrow-slot cylindrical wedgewire screen deployment would be to install the screens in the existing intake channel. While this is feasible from an engineering standpoint, currently the only flow in the canal is from the cooling water flow. Thus to generate a flow past the screens to carry away larvae and debris would require use of additional pumps to induce a current. This would require a flow volume essentially equivalent to that of Units 1, 2 and 8 cooling water flow. There are two issues associated with this approach:

1. The current entrainment of aquatic organisms into the intake channel would be doubled. Although 43.5% of the organisms would be excluded, the overall number of organisms that would be entrained into the intake channel would more than double, resulting in a net increase in entrainment into the intake channel.

2. For the 43.5% of the organisms excluded, there is likely to be significant additional mortality from exposure to the thermal discharge and water quality conditions in the San Gabriel River. The bulk of the entrainment at Haynes takes place in summer when the thermal impacts to the larvae would be greatest.

The result is that while this option is practical from an engineering standpoint it is not practical from a biological standpoint to reduce overall entrainment mortality.

In terms of using fine-mesh modified traveling water screens, the expected performance would be the same as that projected for Harbor (i.e., <2.5%). This does not include potential additional mortality from re-entrainment of larvae returned to Alamitos Bay or mortality from exposure to the Harbor and Alamitos thermal discharges and poor water quality if the larvae are routed to the San Gabriel River.

The result is that neither modified fine-mesh traveling water screens nor narrow-slot cylindrical wedgewire screens are practical interim technologies to reduce impingement and entrainment. However, since the amended policy has gone into effect, LADWP has reduced Haynes cooling water flow by 45% resulting in an equivalent reduction in entrainment. Further, LADWP plans to fully mitigate remaining entrainment losses through mitigation as required by Section 2.C.3 of the Policy. This level of reduction is likely to provide greater reductions in entrainment and impingement that either of the technologies presented here.

5.3 Consideration of Interim Impingement Mortality Reduction Only Technologies for Harbor and Haynes

This report concerned on an evaluation of interim entrainment mortality reduction alternatives. Based on results of the evaluation, LADWP intends to prepare a similar evaluation of technologies to reduce impingement mortality. However, this report does provide the results of the first year, of a new two year study to estimate current impingement mortality levels.

5.3.1 Harbor Impingement Mortality

Results of a one year impingement study conducted at Harbor in 2006 estimated annual impingement to be 8,851 fish. In anticipation of the new federal §316(b) Rule LADWP initiated a new impingement study in April, 2012. The new impingement study differs from the 2006 study in two ways. First, in the original study a 24 hour sampling event was comprised of 4 six hour sampling events, while in the new study there is a single 24 hour sampling event. Second, sampling frequency was once per week for one year and the new study frequency is once every other week for two years. Table 5.5 provides a comparison of estimated annual impingement numbers and biomass from the 2006 study to the first year of sampling in the new study. While the 2006 estimates are based on 50 sampling events and the new study estimates are based on 25 sampling events, the estimates from both studies were calculated using actual flows over the one year periods. In the 2006 study, 25 different species were collected compared to 17 species in the new study. Round stingray remained the dominant species collected during impingement sampling making up 69.5% of the estimated totals by number in 2006 and 40% in the new study. However, northern anchovy made up only 0.3% of the estimated impingement in 2006 but made up 32.7% of the estimated totals in the new study and were the second most abundant fish in the impingement sampling. The estimated annual impingement declined from 8,851 fish in 2006 to 2,315 in the current study (73.8% fewer fish impinged). The overall cooling water flow during the one year period of the new study was only 6% less than during the 2006 study. The majority of impingement during the 2006 study occurred from August to December as shown in Figure 5-1. A comparison of Harbor cooling water flow is provided in Figure 5-2 and shows little difference in flows during this period for the two studies. In fact, flows were 5.7% higher during this period for the new study compared to the 2006 study. Thus the difference between the 2006 estimate and the current estimate is likely due primarily to inter-annual variability. The average estimated annual impingement from the two years was 5,375 fish.

Round stingray remain the dominant species making up 40.0% of the annual impingement, followed by northern anchovy (32.7%), shiner perch (9.6%), spotted kelpfish (4.5%) and black perch (3.5%). Together these five species made up over 90% of the annual impingement. Harbor does not heat treat the intake so there is not additional mortality associated with heat treatments. Impingement for Harbor is among the lowest for California's once-through cooled facilities, which is likely due, in part, to the relatively low approach velocity (i.e., 0.4 fps) at the traveling water screens and not using heat treatments to clean the cooling water system. The additional year of data from the sampling currently being conducted will help verify if the differences between the 2006 and 2012/2013 studies represent inter-annual variability or new baseline levels that could be due to a variety of factors related to changing ocean conditions or changes in the harbor complex.

Table 5-5 – Estimated annual impingement and biomass for 50 weekly 24 hour sampling events conduced from January –December, 2006, and 25 biweekly 24 hour sampling events conducted between April 2012 and April 2013 at the Harbor Generating Station (estimates based on actual cooling water flow). Only the 17 fish species collected during 2012/2013 are listed in the table.

Species	Common Name	2006 Number Impinged	2012/12 Number Impinged	Average Annual Impingement (number)	2006 Impingement Biomass (kg)	2012/13 Impingement Biomass (kg)	Average Annual Impingement (biomass (kg))
Urobatis halleri	round stingray	6,150	926	3,538.0	1,231.68	133.27	682.5
Engraulis mordax	northern anchovy	24	756	390.0	0.02	0.46	0.24
Embiotoca jacksoni	black perch	646	80	363.0	18.49	0.47	9.48
Cymatogaster aggregate	shiner perch	390	223	306.5	3.36	3.10	3.23
Porichthys myriaster	specklefin midshipman	484	26	255.0	11.96	0.03	5.6
Gibbonsia elegans	spotted kelpfish	158	105	131.5	1.49	0.40	0.945
Heterostichus rostratus	giant kelpfish	192	30	111.0	15.73	0.75	0.375
Acanthogobius flavimanus	yellowfin goby	163	14	88.5	3.15	0.09	1.62
Phanerodon furcatus	white seaperch	115	13	64.0	4.12	0.01	2.065
Tridentiger trigonocephalus	chameleon goby	52	33	42.5	0.28	0.10	0.16
Atherinops affinis	topsmelt	7	37	22.0	0.20	0.17	0.185
Pleuronichthys verticalis	hornyhead turbot	34	5	19.5	3.97	0.09	2.03
Syngnathus leptorhynchus	bay pipefish	20	12	16.0	0.07	0.01	0.04
Hypsurus caryi	rainbow seaperch	0	16	8.0	0.00	0.12	0.06
Amphistichus argenteus	barred surfperch	0	13	6.5	0.00	0.01	0.005
Hypsoblennius gilberti	rockpool blenny	0	13	6.5	0.00	0.04	0.02
Sardinops sagax	Pacific sardine	0	13	6.5	0.00	0.35	0.175
Total for Species Listed		8,435	2,315	5,375.0	1,294.51	139.47	708.73
Total Abundance All Species)		8,851	2,315		1,316.60	139.47	
Number of Species		25	17		25	17	

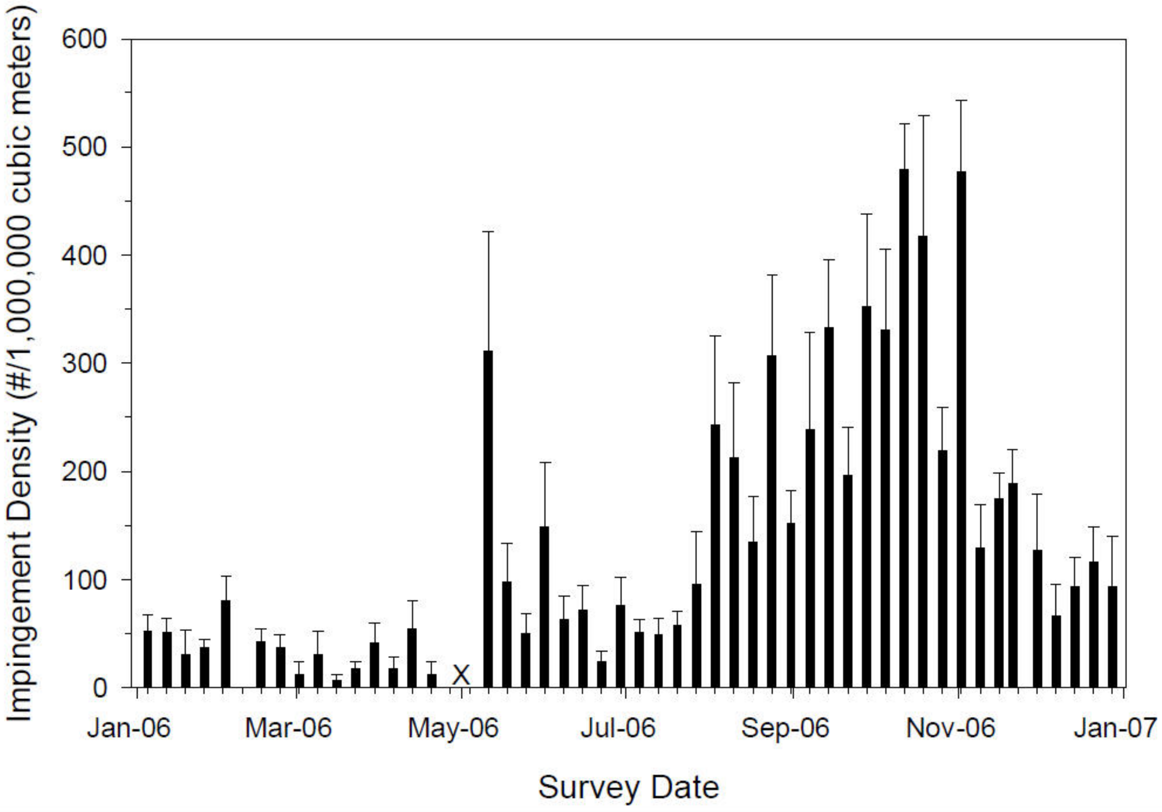

Figure 5-1 – Distribution of Harbor Generating Station impingement during the 2006 impingement study.

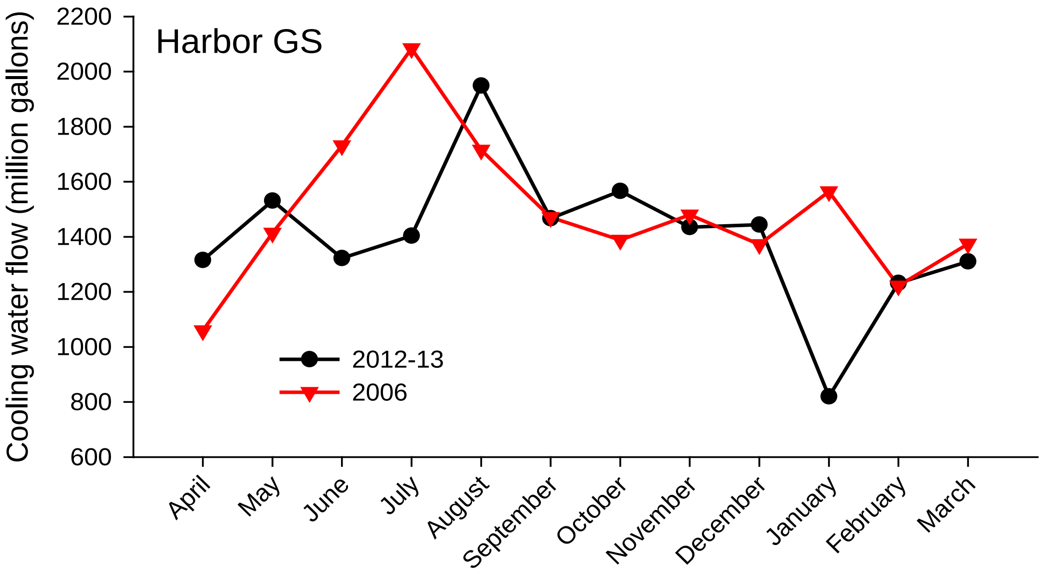

Figure 5-2 – Comparison of Harbor Generation Station actual cooling water flow during the 2006 and April 2012 to April 2013 study

5.3.2 Haynes Impingement Mortality

Data from a one year impingement study conducted at Haynes in 2006 were used to calculate annual impingement estimates of 31,226 finfish for Units 1, 2, 3 and 4, and 53,442 finfish for all Units (i.e., including the now retired Units 5 and 6). In anticipation of the new federal §316(b) Rule LADWP initiated a new impingement study in April 2012. Similar to the sampling at Harbor, the new impingement study differs from the 2006 study in having sampling reduced from four times per 24 hours every week, to once per 24 hours every two weeks. Table 5-6 provides a comparison between estimated annual impingement numbers from the 2006 study to the first year (April 2012–April 2013) of sampling in the new study. While the 2006 estimates are based on 50 sampling events and the new study estimates are based on 25 sampling events, the estimates from both studies were calculated using actual flows over the one year periods. In the 2006 study, 22 different species were collected compared to 13 species in the new study. Queenfish were the dominant species in both study periods making up 60.5% of the total estimated impingement in 2006 and 86.8% in the new study. The impingement estimates declined from 31,226 (Units 1,2 3 and 4) in 2006, to 11,091 in the current study (64.5% fewer fish impinged) for Units 1, 2 and 8 (Unit 8 replaced Units 3 and 4), for a reduction of 79.2% (i.e., includes Units 5 and 6 impingement). The seasonal changes in impingement levels over the course of the 2006 study in Figure 5-3 show that the highest impingement levels occurred found from mid-June through October. Figure 5-4 shows a comparison of flows for Units 1, 2, 3 and 4 (Units 3 and 4 are now Unit 8a and 8b). The overall cooling water flow during the 2012/2013 study period was quite similar to the 2006 study for Units 1 and 2 that account for almost 99% of the impingement. The only major difference was during April for Unit 1 and April and May for Unit 2, which were months when impingement levels were low relative to the fall period (Figure 5-3). Therefore, since flows were relatively similar for the two study periods the most likely cause of the difference is inter-annual variability in fish abundance. The average estimated annual impingement from the two years was 20,036 fish. The additional year of data from the sampling currently being conducted will help verify if the differences between the 2006 and 2012/2013 studies represents inter-annual variability or new baseline levels that could be due to a variety of factors related to changing ocean conditions or changes in Alamitos Harbor.

Table 5.7 presents data from the first year of the new impingement study separately for Units 1, 2 and 8 (intakes a and b for Unit 8). As noted in the table, nearly all of the impingement (i.e., almost 99%) occurred at Units 1 and 2 that are currently targeted for conversion to dry cooling by the end of 2023.

Table 5-6 - Estimated annual impingement and biomass for 50 weekly 24 hour sampling events conduced in 2006 and 25 biweekly 24 hour sampling events conducted between April 2012 and April 2013 at the Haynes Generating Station (estimates based on actual cooling water flow.

Species	Common Name	2006 Impingement Units 1,2,3 and 4	2012/13 Impingement Units 1, 2 and 8	Average Annual Impingement for Units 1, 2 and 8
Seriphus politus	queenfish	18,895	9,629	14,262.0
Engraulis mordax	northern anchovy	3,942	221	2,081.5
Atherinops affinis	topsmelt	3,196	113	1,654.5
Syngnathus leptorhynchus	bay pipefish	1,399	268	833.5
Anchoa delicatissima	slough anchovy	336	60	198.0
Leptocottus armatus	Pacific staghorn sculpin	320	14	167.0
Leuresthes tenuis	California grunion	208	97	152.5
Porichthys myriaster	specklefin midshipman	181	42	111.5
Heterostichus rostratus	giant kelpfish	39	155	97.0
Urobatis halleri	round stingray	128	28	78.0
Gibbonsia elegans	spotted kelpfish	86	29	57.5
Embiotoca jacksoni	black perch	57	43	50.0
Syngnathus californiensis	kelp pipefish	7	87	47.0
Gillichthys mirabilis	longjaw mudsucker	50	35	42.5
Pleuronichthys guttulatus	diamond turbot	63	14	38.5
Hypsoblennius gilberti	rockpool blenny	10	59	34.5
Phanerodon furcatus	white seaperch	35	28	31.5
Atherinopsis californiensis	jacksmelt	21	14	17.5
Cosmocampus arctus	snubnose pipefish	0	29	14.5
Syngnathus exilis	barcheek pipefish	0	28	14.0
Paraclinus integripinnis	reef finspot	7	14	10.5
Paralabrax maculatofasciatus	spotted sand bass	0	15	7.5
Myliobatis californica	bat ray	0	14	7.0
Hypsoblennius gentilis	bay blenny	0	14	7.0
Lepidogobius lepidus	bay goby	0	14	7.0
Platyrhinoidis triseriata	thornback	0	14	7.0
Paralabrax nebulifer	barred sand bass	0	13	6.6
Total for Species Listed Above		28,980	11,091	20,035.6
Total Abundance for All Species		31,226	11,091	
Total Number of Species		22	13	

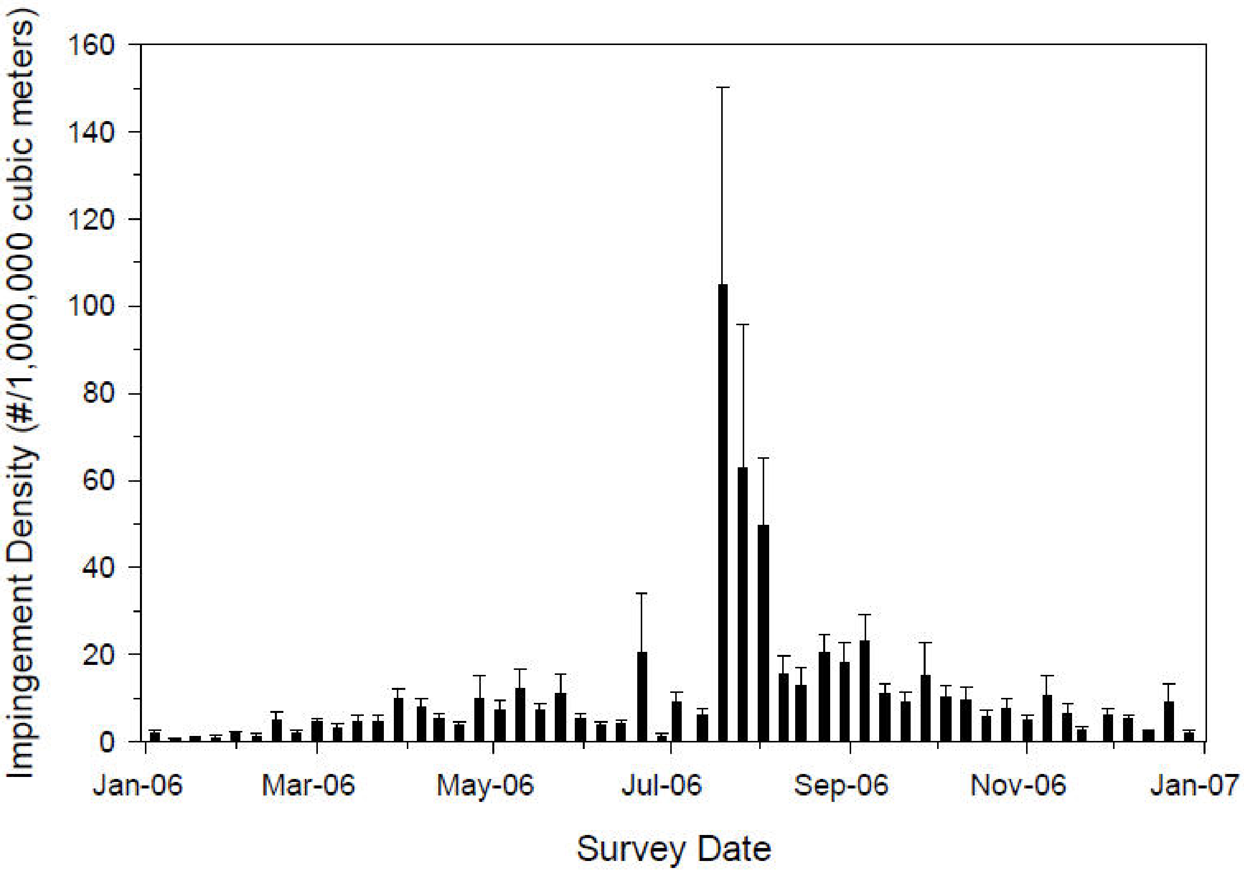

Figure 5-3 – Impingement distribution at the Haynes Generating Station over the course of the 2006 impingement study

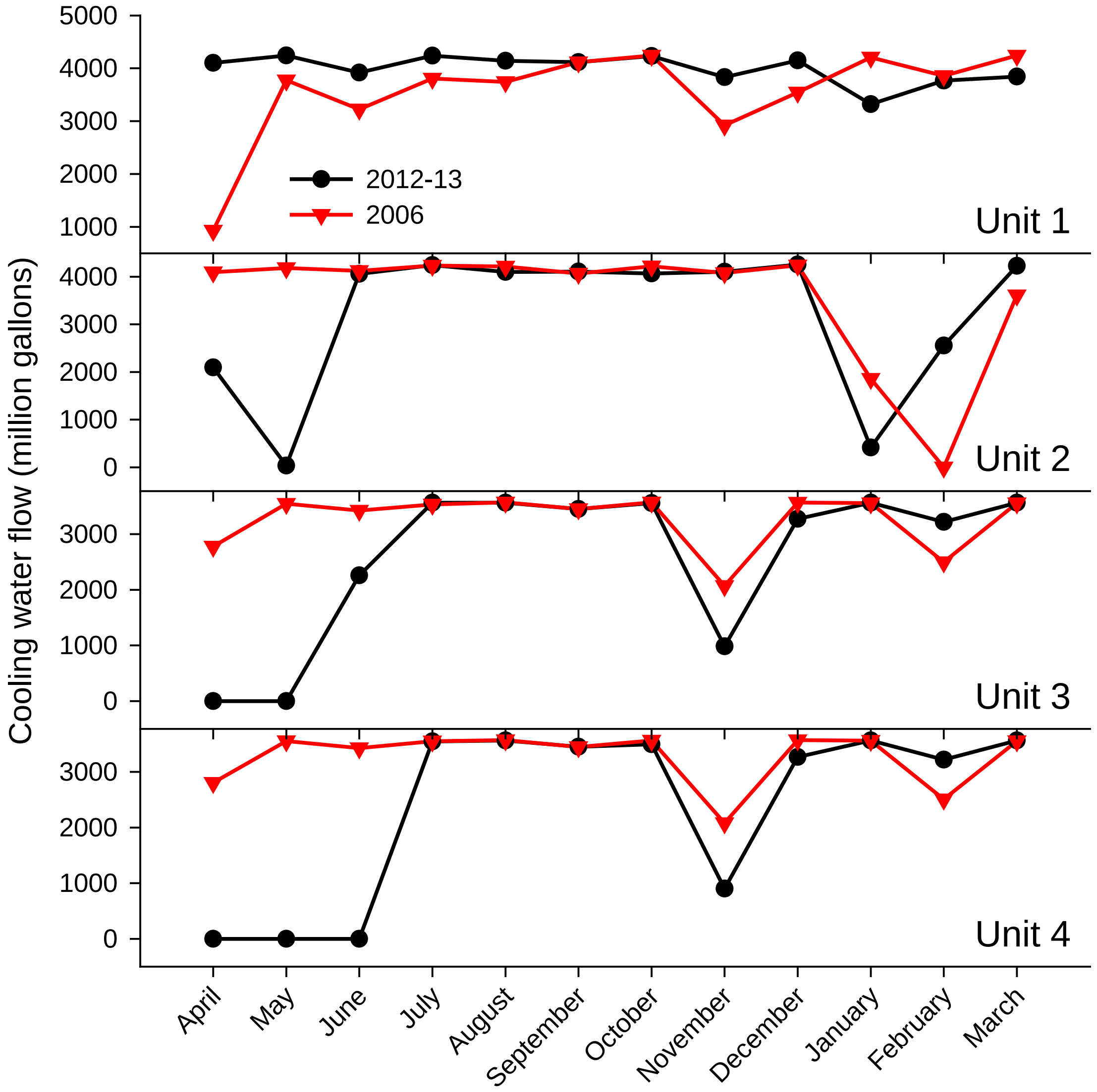

Figure 5-4 – Comparison of Haynes Generation Station cooling water flows for Units 1, 2, 3 and 4 during the 2006 study and the April 2012 to April 2013 study. At the time of the current study the Units 3 and 4 intakes are now the Unit 8a and 8b intakes

Table 5-7 – Estimated annual fish impingement by Unit/Intake based on the first year of the new impingement study (April, 2012 to April, 2013) at the Haynes Generating Station

Common Name	Unit 1 2012/13	Unit 2 2012/13	Unit 8a 2012/13	Unit 8b 2012/13	Total 2012/13 Impingement
queenfish	8,901	715	0	13	9,629
northern anchovy	207	0	0	14	268
topsmelt	43	70	0	0	221
bay pipefish	198	56	0	14	155
slough anchovy	28	32	0	0	113

Pacific staghorn sculpin	14	0	0	0	97
California grunion	84	0	13	0	87
specklefin midshipman	42	0	0	0	60
giant kelpfish	114	13	0	28	59
round stingray	28	0	0	0	43
spotted kelpfish	14	15	0	0	42
black perch	28	15	0	0	35
kelp pipefish	56	31	0	0	29
longjaw mudsucker	35	0	0	0	29
diamond turbot	0	14	0	0	28
rockpool blenny	28	31	0	0	28
white seaperch	28	0	0	0	28
jacksmelt	14	0	0	0	15
snubnose pipefish	16	0	0	13	14
barcheek pipefish	0	14	0	14	14
reef finspot	14	0	0	0	14
spotted sand bass	0	15	0	0	14
bat ray	0	0	0	14	14
bay blenny	14	0	0	0	14
bay goby	14	0	0	0	14
thornback	14	0	0	0	14
barred sand bass	0	13	0	0	13
Total Impingement	9,934	1,034	13	110	11,091
Percent of Annual Impingement	89.6%	9.3%	0.1%	1.0%	100.0%

6 SUMMARY AND CONCLUSIONS

The Harbor and Haynes Generating Stations are both planning to eliminate use of once-through cooling. However, due to extended compliance schedules these facilities are subject to additional requirements. This evaluation considered all currently available approaches and technologies to reduce both impingement and entrainment mortality in conformance with Section (2)(C)(4)(b) of the California cooling water policy amendment issued July 19, 2011. The evaluation included consideration of new technologies and improvements to existing technologies.

6.1 Entrainment Reduction

This evaluation was based on five species of concern that made up over 95% of the entrainment at both facilities and included blennies, croaker, gobies, northern anchovy and silversides (not entrained at Harbor). The results of the evaluation identified two technologies, fine-mesh modified traveling water screens and narrow-slot cylindrical wedgewire screens as potential technologies for further evaluation. Modified traveling water screens with a fish return system were selected, since they were identified by the EPA as BTA for impingement in the proposed rule and EPRI research has shown fine-mesh modified traveling water screens can provide relatively good performance depending on the species of concern and lifestage. Narrow-slot cylindrical wedgewire screens were selected due to their relatively good biological performance, depending on the lifestage and ambient source waterbody hydraulic conditions.

An engineering analysis determined that fine-mesh screens with a 0.5 mm mesh could be installed at either facility. However due to the small size of the entrained species, less than half of the entrained larvae would be retained on the screens for Haynes while a little over a quarter of the larvae would be retained at Harbor. Of those larvae retained, it is estimated that less than 2.5 % would survive the collection process due to lack of musculature and scales. Because of their expected poor biological performance, fine-mesh modified traveling water screens are not considered practical for use as interim control measures.

An engineering analysis of narrow-slot (0.5 mm) cylindrical wedgewire screens indicates that while they could be deployed at either facility, necessary permissions and permits would be highly problematic at Harbor due to the use of Slip 5 for ship dockage. Additionally, biological performance is expected to be poor at both locations. For Harbor, exclusion performance is estimated to be less than 25% for entrainment with a significant risk that larvae may be re-entrained due to low ambient water currents in Slip 5. For Haynes, exclusion performance is estimated to be less than 44%. Deployment options for Haynes are limited to placement of screens in the intake channel. Additional significant entrainment mortality is expected if fish are returned to the marina due to re-entrainment at either Alamitos or Haynes intakes or from exposure to the heated cooling water discharges from Alamitos and Haynes, if organisms are routed to the San Gabriel River. Because of the expected poor biological performance, due to the small size of entrainable life stages of the species of concern and site-specific hydraulic and/or water quality conditions, this technology is also not considered appropriate for interim entrainment and impingement reduction at these two facilities.

A flow reduction of 50% has already been achieved at Haynes, 45% of which took place after the July 2011 interim Policy condition that went into effect; and the current schedule to convert Units 1 and 2 to dry cooling is scheduled to be completed prior to the requirement for interim impingement further reduction flow by 77%. The associated 77% entrainment reduction should further minimize entrainment on an interim basis. Further, LADWP has a target date of 2023 for conversion of Units 1 and 2 to closed-cycle cooling.

6.2 Impingement Mortality Reduction

New two year impingement studies are underway at both Harbor and Haynes. Results from the first year of the study indicate a significant reduction in impingement at both facilities compared to the prior 2006 study. The estimated annual impingement of finfish at Harbor was 73.8% lower than the estimate from the 2006 study. The reduction in impingement is likely attributable to inter-annual variability. The average annual impingement estimate of 5,375 finfish reflects the variation between years. There was also a reduction at Haynes where the estimate of annual finfish impingement from the recent study was 73.8% lower than the estimate from 2006 based on data from comparable units (i.e., Units 1, 2 and 8 - the Unit 8 intake was used for Units 3 and 4 prior to their retirement). The average annual impingement estimate of 20,036 finfish reflects the variation between years. While Haynes does heat treat, it is done in a manner that avoids impingement mortality and thus that source of impingement mortality is not an issue for either facility. Based on the results of the evaluation of technologies with the potential to reduce both impingement and entrainment, LADWP plans to conduct a similar evaluation of technologies only reduce impingement mortality.

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