TENERA Environmental

April 9, 2015

Ms. Jeanine Townsend, Clerk to the Board
State Water Resources Control Board
1001 I Street, 24th Floor
Sacramento, CA 95814

Subject: Comment Letter on March 20, 2015 Ocean Plan Desalination Amendment

Dear Board Members:

Thank you for the opportunity to provide comments on the latest draft of the Draft Amendment to the Water Quality Control Plan for Ocean Waters of California Addressing Desalination Facility Intakes, Brine Discharges, and to Incorporate Other Nonsubstantive Changes (Amendment), which released for comment on March 20, 2015. The staff is to be commended on the large amount of work they have done on responding to comments and incorporating revisions into the Amendment. As a former member of Expert Review Panels for this Amendment and the OTC Policy, I was impressed by the extent of the independent outside expert review that was done in preparing the latest draft of the Amendment.

My comments on the revisions to the Amendment are related to the addition of the text at the end of Section 2.e.(1)(a) on the application of APF, especially the use of the 95th percentile value to estimate the level of required mitigation, copied below.

> (a) For operational mortality related to intakes, the report shall include a detailed entrainment study. The entrainment study period shall be at least ~~36~~ 12 consecutive months and sampling shall be designed to account for variation in oceanographic conditions and larval abundance and diversity such that abundance estimates are reasonably accurate. At their discretion, the regional water boards may permit the use of existing entrainment data from the facility to meet this requirement. Samples must be collected using a mesh size no larger than 335 microns and individuals collected shall be identified to the lowest taxonomical level practicable. ~~Additional samples shall also be collected using a 200 micron mesh to provide a broader characterization of other entrained organisms.~~ The ETM/APF analysis* shall be representative of the entrained species collected using the 335 micron net. The APF* shall be calculated using a one-sided, upper ~~90~~ 95 percent confidence ~~level~~bound for the 95th percentile of the APF distribution.

I shall attempt to provide a succinct summary of my concerns regarding the inclusion of this language in the Amendment. I would first like to point out that the language in the last sentence of the section does not reflect the approach used in the SED which uses an estimate of the 95th percentile value from a set of Area of Production Foregone (APF) estimates. A more detailed appraisal of the problems on the use of APF can be found in a guidance document that Tenera has prepared on the development of mitigation programs for desalination plant intakes through a grant from the WateReuse Research Foundation. I have included excerpts from the final report for the project, which is nearing completion, as an attachment to this letter. The attachment includes the Executive Summary from the report, and the sections relevant to the application of the Empirical Transport Model (ETM) and APF in the impact assessment and mitigation scaling process, respectively. The larger report reviews programs used to mitigate for the effects of ocean intakes, including for projects in California. The report also reviews the different approaches used for scaling mitigation, including APF. The conclusions from the report support the use of ETM and APF as the preferred approaches for impact assessment and mitigation scaling, respectively.

While, the WateReuse Research Foundation report does support the use of ETM and APF, there are details of the methodology that are still open to discussion. Most of the development of the ETM and APF has been based on work by Dr. Peter Raimondi and me, and we had hoped to work together on closing some of these areas of disagreement through our collaboration on the WateReuse Research Foundation project. Unfortunately, our schedules have limited our ability to collaborate on the project. I have recently spoken with Dr. Raimondi and he is in agreement that there is still an opportunity to resolve some of the areas of disagreement through our collaboration on the WateReuse Research Foundation project. This same approach was used on the development of the intake impact assessment report that was prepared for the California Energy Commission and has been the *de facto* guidance document for these types of studies in California.[1] The resulting document from the WateReuse Research Foundation project would be of great value to state resource agencies as additional desalination projects are considered for development along the coast.

One of the sources of disagreement regarding the application of APF is the statistical use of the estimates of APF. The ability to generate data from an ETM-based intake assessment that could provide the data necessary for a statistical analysis of APF will be highly site and study dependent. Using the approach provided in the Amendment and SED, the amount of additional acreage required for mitigation is directly related to the number of species analyzed, and not as stated on page 91 of the SED – "The amount of additional acreage needed will largely depend on how well the study was done." Increased confidence in the APF estimates from a study is more dependent on the quality

[1] Steinbeck, J. R.; Hedgepeth, J., Raimondi, P.; Cailliet, G.; Mayer, D. L. 2007. Assessing power plant cooling water intake system entrainment impacts. California Energy Commission; CEC-700-2007-010.

of the underlying data and ETM estimates than the number of taxa included in the analysis.

The problem of emphasizing the number of species instead of data quality is reflected in the estimates of the 95th percentile value provided in the SED for the two example data sets. The 95th percentile value for the data set with ten species is 97.7 acres and the value for the data set with 20 species is 87.9 acres. The decrease between the two estimates is an expected outcome due to the differences in the sample size used in the two data sets. Normally, when estimating the mean value for a population, the confidence in the estimate of the average is increased as more data are included in the sample. The assumption of the approach provided in the SED is based on treating the APFs as replicate estimates that ". . . are representative of all species present at that location, even those that were not directly measured." The APF estimates cannot be treated as if they were all equivalent independent replicates using conventional statistical techniques. Each APF estimate is calculated using a complex set of underlying data that varies among species, but may also overlap with data from other species. This complicates any interpretation of a set of APF estimates, since they should not be treated as equivalent data points as would be required of any standard statistical sample.

There are several factors which can affect the underlying quality of the data used in the calculation of APF. As a result, ETM estimates, which are the basis for the calculation of APF, are only calculated for a few taxa on many studies. This is partially due to the large changes in the composition and abundance of fish larvae through the year. These factors exist regardless of the quality of the study. It may still be possible to calculate ETM estimates for a large number of species, but the underlying confidence in some of the estimates will be very low. Based on the approach in the SED, if enough species were analyzed the 95% percentile value from the resulting APF values could be reduced regardless of the quality of the underlying data.

On the basis of these significant, and currently unresolved methodological details, I would encourage the Board staff to recommend that the last sentence of Section 2.e.(1)(a) in the Amendment be deleted. This will not weaken the policy position and provides an opportunity to develop the details of an approach that ensures that adequate compensation is provided to address the effects of desalination plant intakes. It would also provide the opportunity to explore techniques to ensure that the underlying complexities of the ETM are incorporated into the final APF estimates.

Thank you for the opportunity to provide comments on the latest draft of the Amendment. As I have mentioned, Dr. Raimondi has agreed to work on resolving these issues, and I look forward to working with him and others on developing an approach that will provide a strong basis for any mitigation that might be required under the Amendment.

Sincerely,

John Steinbeck
Vice President

Attachment: WateReuse Research Foundation Report Summary

Development of Habitat Restoration Programs for the Mitigation of Impingement & Entrainment Effects from Intakes for Seawater Desalination Facilities

Mr. John Steinbeck;
Dr. Joseph Phelan; &
Ms. Carol Raifsnider
Tenera Environmental

EARLY RELEASE DOCUMENT

WateReuse Research Foundation
Alexandria, VA

Disclaimer

This report was sponsored by the WateReuse Research Foundation. The Foundation, its Board Members, and the project cosponsors assume no responsibility for the content of this publication or for the opinions or statements of facts expressed in the report. The mention of trade names of commercial products does not represent or imply the approval or endorsement of the WateReuse Research Foundation, its Board Members, or the cosponsors. This report is published solely for informational purposes.

For more information, contact:

WateReuse Research Foundation
1199 North Fairfax Street, Suite 410
Alexandria, VA 22314
703-548-0880
703-548-5085 (fax)
www.WateReuse.org/Foundation

Printed in the United States of America

About the WateReuse Research Foundation

The mission of the WateReuse Research Foundation is to conduct and promote applied research on the reclamation, recycling, reuse, and desalination of water. The Foundation's research advances the science of water reuse and supports communities across the United States and abroad in their efforts to create new sources of high quality water for various uses through reclamation, recycling, reuse, and desalination while protecting public health and the environment.

The Foundation sponsors research on all aspects of water reuse, including emerging chemical contaminants, microbiological agents, treatment technologies, reduction of energy requirements, concentrate management and desalination, public perception and acceptance, economics, and marketing. The Foundation's research informs the public of the safety of reclaimed water and provides water professionals with the tools and knowledge to meet their commitment of providing a reliable, safe product for its intended use.

The Foundation's funding partners include the supporters of the California Direct Potable Reuse Initiative, Water Services Association of Australia, Pentair Foundation, and Bureau of Reclamation. Funding is also provided by the Foundation's Subscribers, water and wastewater agencies, and other interested organizations.

Foreword

The WateReuse Research Foundation, a nonprofit corporation, sponsors research that advances the science of water reclamation, recycling, reuse, and desalination. The Foundation funds projects that meet the water reuse and desalination research needs of water and wastewater agencies and the public. The goal of the Foundation's research is to ensure that water reuse and desalination projects provide sustainable sources of high-quality water, protect public health, and improve the environment.

An Operating Plan guides the Foundation's research program. Under the plan, a research agenda of high-priority topics is maintained. The agenda is developed in cooperation with the water reuse and desalination communities including water professionals, academics, and Foundation subscribers. The Foundation's research focuses on a broad range of water reuse and desalination research topics including:

- Defining and addressing emerging contaminants, including chemicals and pathogens
- Determining effective and efficient treatment technologies to create 'fit for purpose' water
- Understanding public perceptions and increasing acceptance of water reuse
- Enhancing management practices related to direct and indirect potable reuse
- Managing concentrate resulting from desalination and potable reuse operations
- Demonstrating the feasibility and safety of direct potable reuse

The Operating Plan outlines the role of the Foundation's Research Advisory Committee (RAC), Project Advisory Committees (PACs), and Foundation staff. The RAC sets priorities, recommends projects for funding, and provides advice and recommendations on the Foundation's research agenda and other related efforts. PACs are convened for each project to provide technical review and oversight. The Foundation's RAC and PACs consist of experts in their fields and provide the Foundation with an independent review, which ensures the credibility of the Foundation's research results. The Foundation's Project Managers facilitate the efforts of the RAC and PACs and provide overall management of projects.

This report provides a preview of a comprehensive overview of the implementation of compensatory mitigation for the effects of impingement and entrainment (IM&E) due to desalination plant intakes in coastal and estuarine waters. The content of this summary report is designed to be relevant to [proIM&E mitigation Through the process of reviewing previous IM&E compensatory mitigation programs and considering the wider body of knowledge on compensatory mitigation programs, this report identifies generic guidance for using an Empirical Transport Model (ETM) and Area Production Foregone (APF) approach to inform an IM&E compensatory mitigation program for future desalination plant projects. The report examines, in detail, the method of scaling compensatory mitigation projects with these two methodologies. This detailed examination of ETM and APF provides discussion and examples of specific approaches that can be applied to assessing entrainment impacts and scaling compensatory mitigation projects with the aim of presenting a robust, objective framework for designing and delivering an IM&E compensatory mitigation program for desalination plant projects.

Douglas Owen
Chair
WateReuse Research Foundation

Melissa Meeker
Executive Director
WateReuse Research Foundation

Acknowledgments

This project was funded by the WateReuse Research Foundation.

The members of the Tenera project team, which included the principal authors of the report John Steinbeck, Joe Phelan, and Carol Raifsnider, as well as Barbie Dugan, Chris Ehrler, and Tessa Lange want to thank the WateReuse Research Foundation for obtaining and providing the funding for this project. We especially want to thank Kristan Cwalina at the WateReuse Research Foundation for all of her help with the management of the project, project deliverables and coordinating Project Advisory Committee (PAC) meetings. We also want to thank the members of the PAC for their helpful comments during the preparation of this report. Finally, we want to thank all of the participating agencies for contributing matching funding and their review of the final report, as well as Dr. Peter Raimondi at the University of California, Santa Cruz for his helpful comments on the report.

Principal Investigator
John Steinbeck, *Tenera Environmental*

Project Team
Joe Phelan, *Tenera Environmental*
Carol Raifsnider, *Tenera Environmental*
Barbie Dugan, *Tenera Environmental*
Chris Ehrler, *Tenera Environmental*
Tessa Lange, *Tenera Environmental*

Participating Agencies
Contra Cost Water District
DeepWater Desal, LLC
East Bay Municipal Utility District
Municipal Water District of Orange County
West Basin Municipal Water District

Project Advisory Committee
Dr. John Balletto, *John H. Balletto, LLC*
Mr. D. Shane Beck, *MBC Applied Environmental Sciences*
Mr. Tim Hogan, *Alden Laboratory*
Ms. Heidi Luckenbach, *City of Santa Cruz*
Mr. Nikolay Voutchkov, *Water Globe Consulting*
Mr. John Whitler, *Water Research Foundation*

Report Preview

This document is part of a project funded by the WateReuse Research Foundation that is pertinent to the considerations currently underway in California on the implementation of an amendment to the State of California Ocean Plan for regulating desalination plant intakes. A preview of the final project report funded by the WateReuse Research Foundation (the Final WateReuse Report), which is in the final stages of preparation, is presented in this report. This report includes the Executive Summary of the Final WateReuse Report as well as an explanation with examples of the Empirical Transport Model (ETM) approach for assessing entrainment losses and the Area of Production Foregone (APF) approach for scaling compensatory mitigation projects. The use of the APF for scaling compensatory mitigation projects is based on the outcome of the ETM process. These explanations and the accompanying examples of ETM and APF are taken from the Final WateReuse Report.

The information in the Final WateReuse Report will include the following:

Chapter 1 identifies and describes proposed and operating desalination and power plant projects in terms of their impingement mortality and entrainment (IM&E) compensatory mitigation programs. This chapter describes the facilities themselves and the features of the IM&E compensatory mitigation programs associated with those facilities. Restoration as compensatory mitigation is an established principle and its implementation has a broad theoretical and practical background.

Chapter 2 provides a detailed review of compensatory mitigation approaches taken in light of their success. Success is measured in terms of compliance with policy directives under which the compensatory mitigation is required. Chapter 2 includes a full review of the policy and legislative remits that relate to compensatory mitigation programs.

Chapter 3 builds on the reviews in Chapters 1 and 2 to provide guidelines for implementing an IM&E compensatory mitigation program at the project level for a desalination facility.

Chapter 4 provides a detailed review of scaling approaches that have been applied to the design of restoration projects across a broad range of environmental effects, from IM&E to wetland destruction and oil spills. This includes a critical analysis of the application, and applicability, of these scaling methods in relation to IM&E effects. Scaling is a fundamental step in designing a compensatory mitigation program and successfully fulfilling the key mitigation program objective of compensating for environmental losses.

Finally, Chapter 5 provides high level guidance on the design and implementation of a monitoring program to be instigated during the delivery of a restoration project. A well- designed and implemented monitoring program for a restoration projects is a fundamental contributor to the successful delivery of any compensatory mitigation program.

Executive Summary

This executive summary is taken from the Final WateReuse Report and refers directly to the content of that report.

The objectives of this report are to provide a comprehensive overview of the implementation of compensatory mitigation for the effects of impingement mortality and entrainment (IM&E) due to the operation of open desalination plant intakes in coastal and estuarine waters. Through the process of reviewing previous IM&E compensatory mitigation programs and considering the wider body of knowledge on compensatory mitigation programs, this report identifies generic guidelines that can be applied to an IM&E compensatory mitigation program for future desalination plant projects. The report examines, in detail, the method of scaling compensatory mitigation projects based on the types and magnitude of IM&E effects. The process of scaling involves converting effects due to IM&E into units that can be used to develop appropriate mitigation projects. This review provides discussion and examples of specific approaches that can be applied to scaling compensatory mitigation projects with the aim of presenting a robust, objective framework for designing and delivering an IM&E compensatory mitigation program for desalination plant projects.

Although the effects of ocean intakes include both IM&E, the examples in this report largely focus on the effects of entrainment. This is due to recent and current regulatory activity in California on the use of ocean intakes for power plants and desalination facilities, which has largely focused on the effects of entrainment. The focus on entrainment in California is due to the relatively low levels of impingement at most of the existing facilities with ocean intakes, and the availability of intake technologies, such as wedge wire screen, which should dramatically reduce or eliminate the impacts of impingement mortality at desalination facility intakes. Since habitat restoration has not been commonly used to compensate for the effects of ocean intakes, most of the examples in the report are also from California where habitat restoration has been used on several projects. Despite the focus on California, the recommendations in this report would be applicable to ocean intakes in other areas of the country and could be adapted to address the effects of both IM&E.

Compensatory mitigation is defined in this report as measures that are taken to replace or compensate for losses caused by IM&E through some form of habitat restoration. Impingement is defined as the effect of trapping organisms against an intake screen that protects the entrance to a water intake. Entrainment is defined as the passage and subsequent mortality of marine life that enters the desalination plant from the source water through the intake system. The effects of IM&E have direct and indirect impacts on the marine environment due to the loss of the organisms affected.

An IM&E compensatory mitigation project typically involves the creation, enhancement, or restoration of a natural resource that might include a population, habitat or ecosystem. This process includes planning, implementation, and maintenance of the project as well as monitoring of its success and efficiency at replacing the lost resources. Identifying any significant IM&E effects, scaling the effects to some form of mitigation units, and identifying appropriate options for mitigation are crucial first steps in implementing any IM&E compensatory mitigation project.

The majority of environmental assessments and compensatory mitigation projects implemented to address IM&E effects are for intakes at existing power plant facilities. All facilities with IM&E compensatory mitigation programs addressed in this report are located in the U.S. The IM&E compensatory mitigation programs fall into two categories, those that used fish hatcheries and stocking programs, and those that used habitat restoration or enhancement. Out of 75 power plant projects and 41 desalination plant projects identified in this report with coastal and estuarine intakes in the U.S., 17 examples of IM&E

compensatory mitigation programs were identified for detailed examination. The objective of the review of these 17 projects was to provide an assessment of the projects that could be used to develop generic guidelines for IM&E compensatory mitigation programs at desalination plants.

Compensatory mitigation, particularly in the form of habitat restoration, is a policy measure that is implemented frequently through several legislative permitting processes in the U.S. Specifically, §404 of the Clean Water Act (CWA §404) that addresses the management of wetlands, the Natural Resource Damage Assessment (NRDA) process that is applied under the Oil Pollution Act (OPA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and National Pollutant Discharge Elimination System (NPDES) permitting under §316(b) of the Clean Water Act (CWA §316(b)). None of these programs address desalination project development, but their prominence in U.S. environmental policy coupled with their extensive examination and development of implementation practices makes their examination critical to developing guidelines for an IM&E compensatory mitigation program for future desalination plant projects. Although each of these policy programs differs in several ways, some characteristics are universal. These universal characteristics form the basis of the guidelines described in this report. In each case, these programs guide the compensatory mitigation planning process to consider during the following three stages in the process:

1. Determination of impact;
2. Determination of mitigation; and
3. Project implementation and management.

Impact determination begins with an assessment of the losses of resources or habitat, and ends with a decision as to whether there is a need for compensatory mitigation. It is important that a quantitative approach be used to assess impacts because this will provide the necessary understanding of the type and degree of impacts for determining the need for mitigation. The impact determination also provides the basis for assessing the nexus to the impacts required when considering potential restoration projects during the second stage in the process, the determination of mitigation. The data from the impact assessment is also critical in scaling any compensatory mitigation projects. The compensatory mitigation implementation plan, should clearly define the losses, the nexus between the losses and any proposed project, and the scaling approach used to determine the appropriate level of mitigation.

The determination of mitigation begins once the impact determination stage is complete. Establishing the mitigation goals is central to guiding this planning process. Setting mitigation goals is largely determined by the policy context under which the compensatory mitigation program is being implemented. For example, under §404, the stated policy position provided by the regulatory authorities (United States Environmental Protection Agency [USEPA] and United States Army Corps of Engineers [Corps]) requires the restoration or enhancement of wetlands that provide similar wetland functions and acreage to the wetlands that are lost (73 FR 19594-19705). The draft Desalination Amendment to the California Ocean Plan (§L2e) states "*The owner or operator shall fully mitigate for all marine life mortality associated with the desalination facility*." The implication of this policy statement to setting the goals of a compensatory mitigation program is that the marine organisms lost due to IM&E effects (which will primarily include larval, planktonic, and microscopic organisms) must be fully replaced through mitigation. For many planktonic species with little to no habitat association, other than the pelagic ocean environment, it should be clear that it is highly unlikely that full replacement of these entrained organisms could be accomplished through habitat restoration because pelagic ocean habitat cannot be reliably created, restored or enhanced.

The mitigation determination stage primarily involves the identification and selection of projects with potential for meeting the mitigation objectives. Evaluating and selecting compensatory mitigation projects is best performed against a matrix of criteria in order to provide a structured assessment that can be objectively considered by all stakeholder groups. While many potential criteria exist that could be used to form the criteria matrix against which compensatory mitigation projects can be evaluated, three broad categories encompass the key factors that should be considered for selection of a successful IM&E compensatory mitigation project. These three categories include the following:

1. Nexus to impact;
2. Feasibility of a project; and
3. Stakeholder acceptance.

In order to provide documentation of, and a cohesive structure to, an IM&E compensatory restoration program it is recommended that a formal implementation plan be developed early in the program planning process. The recommended format of an implementation plan includes the following:

- Statement of goals;
- Explanation of roles and responsibilities;
- Targeted monitoring and implementation assessment program; and
- Project timelines and allocated budgets.

In the early planning stages, a conceptual model of the restoration project should be included in the plan. As the project develops, the plan should be updated to include more detailed approaches to project implementation. It is expected that development of a plan would be an ongoing process and therefore, the planning process would develop with the project under a process of adaptive management. During planning, the adaptive management process will be influenced by regular review against the project objectives and ongoing findings (i.e., determination and characterization of impacts, identification of alternative restoration projects, etc.). As the compensatory mitigation project is implemented, adaptive management will be informed by a scientific monitoring program.

A further consideration in the implementation of the IM&E compensatory mitigation project is the assurance of long-term stewardship. This is to ensure the IM&E compensatory mitigation fully meets the goals of the project, which is likely to require development, maintenance, monitoring, and management over a period of several years to several decades, and ultimately until the end of the useful life of the desalination plant. In the case of a permanent loss of resources, such as §404-related impacts (i.e., the destruction of wetland habitat), the policy actively promotes self-sustaining restoration projects. However IM&E effects are unlikely to cause permanent impacts beyond the operational life of the intake and therefore, the consideration of long-term stewardship is likely to only extend to the point of desalination plant decommissioning.

Scaling is the process of estimating the acreage and/or costs associated with mitigation restoration. Scaling is fundamental to underpinning the nexus-to-impact of a compensatory mitigation project. As the fundamental basis for providing the nexus-to-impact of a compensatory mitigation project, the process should be transparent and objective and therefore, should involve a quantitative method of scaling. A large variety of scaling approaches exist, although they are all united by the fundamental principle of equating losses with gains. As a consequence of the application of this principle across disparate policy and legislative programs that allow for or require compensatory mitigation, the developers of approaches to implementing compensatory mitigation scaling have devised different terminologies to describe the basic principles. This report proposes to unify the terminology under the term Equivalency Analysis (EA). The process of EA therefore, requires that losses be equated to gains in some manner.

An example of the different terminologies that have developed under different policy and legislative programs is the use of the terms Habitat Equivalency Analysis (HEA) and Resource Equivalency Analysis (REA). These terms are used mainly in the natural resource damage assessment (NRDA) process. The term HEA and REA are synonymous with compensatory mitigation approaches taken to equate losses with gains following major environmental accidents such as oil spills. The core principle behind both REA and HEA is that losses must be equated to gains. The manner by which losses are equated with gains is not prescribed by the guidance on these methods and therefore, these methods can be thought of more as approaches rather than scaling methods.

An alternative approach used in California for several projects, such as the 50 MGD Carlsbad Poseidon Desalination Project is Area of Production Foregone (APF). APF also seeks to equate losses due to entrainment with gains due to habitat restoration. While not a necessity, APF normally does this by estimating habitat equivalencies using empirical data collected and analyzed through an Empirical Transport Model (ETM)-based impact assessment. Differences between APF and EA, such as those discussed by Strange et al. (2012), are actually differences in implementation that are rooted in separate, historical developments and applications of the two methods. All three approaches (HEA, REA and APF as described by Strange et al. [2012]) attempt to balance the losses incurred due to the impact with the gains accrued through restoration.

HEA and REA as described in Strange et al. (2012) require the use of published values of habitat productivity per acreage from the scientific literature to scale gains to losses. This productivity is used to scale absolute entrainment values to equate the entrainment estimates with habitat. However, the published values of habitat productivity from the literature may be from a different location, or taken at a different time, to the implementation of the IM&E compensatory mitigation project. There is no way to determine how representative a published habitat productivity estimate would be of the habitat relevant to the IM&E compensatory mitigation project. APF based on an ETM approach relies on data collected at the location of the potential intake and is therefore, likely to be far more accurate than derived parameters taken from the literature.

When considering the magnitude of an IM&E impact for desalination and subsequently scaling compensatory mitigation to offset losses, a relative assessment approach is more robust to estimation error than an absolute measure. The absolute numbers of larvae entrained will change considerably within and between years due to numerous physical and biological factors which affect levels of larval production and survival. It is critical to have an assessment method such as the ETM for entrainment that provides a relative measure of impact integrated across a year (called proportional mortality [P_M] in the ETM terminology) that should vary much less over time than absolute estimates of impact (such as an estimate of total entrained fishes). Similarly, the APF estimate resulting from ETM for an individual species should also be relatively invariant over time, because while the larval production from an area of habitat within the Source Water Body (SWB) will vary considerably over time, the proportion of the larvae in the source water produced by that area of their habitat should be much less variable.

Even though the core principles underlying HEA and REA are generic, the application of discounting is unique to these two scaling approaches. Discounting is applied on a temporal basis, weighting earlier losses and gains in favor of later losses and gains. This concept is described as being synonymous with interest rates on loans. Presumably this analogy implies that, like money, the value of a resource measured in terms of an absolute metric (e.g., acreage of habitat, stock size of a fishery, etc) declines over time in the same way that the absolute value of money (e.g., U.S. dollars) declines over time as its purchasing power or true value is affected by fiscal factors such as inflation. The basis for the United States National Oceanic and Atmospheric Administration (NOAA) applying a discounting factor in NRDA relates to a consideration of the perception of ecological worth over time. For example, a fisherman waiting for his fishing grounds to recover following an oil spill is painfully aware of the immediacy of the effect to his livelihood and is likely to be unsympathetic to the argument that restoration sometime in the future will offset the losses to the environment in the period immediately following the spill. In this sense, discounting represents that grievance, and can best be understood in terms of the NRDA process. An ends-based perception of the reasoning behind the application of discounting is that it acts as a strong incentive to decision makers, developers, policy makers, and regulators to implement compensatory mitigation projects as early as possible. In relation to IM&E compensatory mitigation, the application of discounting is fundamentally a policy decision. Emerging policy direction in California, for example, indicates no desire to require a discounting approach at this point in the draft policy statements.

The applications of APF in California have all used estimates of intake effects based on ETM. It is important to recognize that the results from an ETM should be considered separately from APF. Although Raimondi (2011) states that P_M is not an intuitive currency for impact assessment, the ETM estimate of P_M is the fundamental basis for any assessment of the environmental impact of entrainment effects. Assessing the environmental impact of entrainment effects is a necessary step in order to determine whether there is a need for compensatory mitigation. The ETM is a robust method for providing this assessment as it provides the same type of information (P_M) used by resource scientists in managing fisheries. The estimates of P_M are similar to estimates of the effects of fishing mortality on a population, and, in this context, can be interpreted relative to other sources of mortality. Another important consideration that only applies to the assessment of impact using the ETM estimate of P_M is that the mortality is occurring to the stock of larvae in the SWB, and not an adult population. Interpreted in this context, an estimate of P_M that is very low relative to other natural sources of mortality, or levels of natural variation, indicates that entrainment effects on that organism are not likely to be significant.

In contrast to P_M, evaluating impacts using APF can potentially distort the interpretation of intake effects. Even though the ETM estimates of P_M may be very small, say 1.0%, the resulting APF estimate may represent a large area, resulting in the impression that entrainment is having a large impact on the population. For example, if the SWB for the species with a P_M = 1.0%, extended over a coastal area of 300 square km (116 square mi), which is representative of many species from studies along the California coast, the resulting APF would equal 30 ha (74 acres), which could be interpreted as a large area of habitat. Conversely, the likelihood that the proportional loss to the larvae would affect the population is unknown when APF alone is considered.

APF estimates for coastal pelagic fishes that are not associated with any specific coastal habitat such as a kelp bed or rocky reef are not very useful in interpreting impacts as they merely restate the ETM estimates of P_M. Using the example above, the P_M estimate of a 0.01 (1.0%) loss of the larvae from the total SWB of 300 square km (116 square mi), would be represented as an APF of 30 ha (74 acres) of coastal waters. Both estimates do not provide any information on the area of habitat necessary to replace the losses to the source water for these fishes.

This limitation on the use of APF is tied to the implicit assumption of the method that a species is limited by available habitat (Strange et al., 2012). The assumption that APF provides an estimate of the amount of habitat that would need to be replaced to compensate for larval production lost due to entrainment (Raimondi, 2011) means that using APF to assess the impact to species that are not associated with a specific habitat is a misrepresentation of the method. This assumption of APF, which also applies to any habitat restoration scaling approach that seeks to increase the larval production by replacing adult habitat, is that the adult population is habitat limited. Habitat limited adult populations are populations that cannot increase any further because the area of habitat which they inhabit is full. By increasing the habitat area, new adults will eventually establish themselves in those areas. It is highly unlikely that populations that are habitat limited are also larval limited. Larval limited populations are populations that cannot increase any further because there are insufficient larvae available to make more adults. Unless a population is larval limited it is unlikely to be affected by entrainment. If it is larval limited it is unlikely to benefit from habitat restoration.

While there can be problems with the interpretation of APF, other methods of scaling often require complex modeling approaches that, although potentially quite accurate, may alienate stakeholder groups during the scaling process because they are technically complex and laden with assumptions.

Furthermore, models such as Adult Equivalent Loss (AEL) and Fecundity Hindcasting (FH) are particularly vulnerable to uncertainty in the model parameters. The very nature of empirically based models makes them less vulnerable to these uncertainties. APF based on the ETM does not require a comprehensive understanding of complex ecosystem modeling approaches and ecological principles. As a result, ETM/APF is more likely to be accepted in a stakeholder-led process than a more technically demanding modeling approach with high potential for uncertainty.

Habitat restoration as compensatory mitigation for IM&E impacts from desalination intakes in coastal and estuarine environments is a viable solution to addressing the sustainable implementation of large-scale coastal desalination. Compensatory mitigation for environmental effects is an established field in many other areas of environmental development planning. As with all project planning activities, early consideration of environmental factors will ensure that implementation progresses smoothly and will increase the likelihood of success. This early consideration should include the identification of goals and objectives as well as the incorporation of stakeholder issues that should continue throughout the process. Objective scaling requires a quantitative approach, and relative approaches such as the ETM/APF are likely to be the most robust scaling methods to apply to IM&E effects because of the highly variable nature of marine populations, particularly planktonic populations subject to entrainment effects.

Once a project has been identified, the successful implementation of a restoration project requires an adaptive management approach. The principles used in a relative approach to project scaling should also be incorporated into the design of a monitoring program that will inform the adaptive management of any restoration program when it comes to implementation. This is done by avoiding the use of absolute performance standards and basing the standards on comparisons with reference locations. An adaptive management approach ensures that if there are unforeseen environmental responses to the measures being implemented by the project, the environmental responses can be addressed with remedial measures. However, the potential need for remedial measures also pose a risk to the success of a compensatory mitigation project, as these remedial measures may impose financial and other burdens that were not anticipated during the planning phase of the compensatory mitigation program. The relative approach to assessment of goals through a monitoring program design provides a way to incorporate the normally high variability in natural marine environments into the goals of the program and to manage the risk associated with adaptive management of restoration project implementation.

Ocean Intake Assessments and Mitigation Scaling in California

This section presents details on the use of ETM for intake assessments and APF for mitigation scaling that are taken from the Final WateReuse Report. All but one of the examples presented in the Final WateReuse Report are from projects in California. These two methodologies, which are explained in more detail in Steinbeck et al. (2007), have been included in regulations recently adopted in California for power plants with once-through cooling,[1] and are included in regulatory language proposed in July 2014 by the California State Water Quality Control Board for desalination plant intakes (Draft Desalination Amendment).[2]

Empirical Transport Model (ETM)

The intake assessments from California presented in the Final WateReuse Report used a modified version of the ETM. The ETM was first proposed by the USFWS to estimate mortality rates resulting from cooling water withdrawals by power plants along the Hudson River in New York (Boreman et al., 1978; and subsequently in Boreman et al., 1981). The ETM provides an estimate of incremental mortality (a conditional estimate of entrainment mortality in absence of other mortality) (Ricker, 1975) based on estimates of the fractional loss to the source water population of larvae represented by entrainment. The conditional mortality is represented as estimates of proportional entrainment (*PE*) that are calculated for each survey and then expanded to predict regional effects on populations using the ETM, as described below. Variations of this model have been discussed in MacCall et al. (1983) and have been used to assess intake impacts at most of the California power plants (MacCall et al., 1983; Steinbeck et al., 2007).

The estimate of *PE* is the central feature of the ETM (Boreman et al., 1981; MacCall et al., 1983). Estimates of *PE* are typically calculated for each taxonomic category (taxon) of fish or shellfish larvae being analyzed. *PE* estimates are calculated for individual surveys as the ratio of the estimated numbers of larvae entrained per day to the larval population estimates within specific volumes of the source water as follows:

$$PE_i = \frac{N_{E_i}}{N_{S_i}} = \frac{\bar{\rho}_{E_i} V_{E_i}}{\bar{\rho}_{S_i} V_{S_i}}, \qquad (1)$$

where N_{E_i} and N_{S_i} are the estimated numbers of larvae entrained and in the sampled source water per day in survey period *i*, $\bar{\rho}_{E_i}$ and $\bar{\rho}_{S_i}$ are the average concentrations of larvae from the intake and source water sampling, respectively, per day in survey period *i*, and V_{E_i} and V_{S_i} are the estimated volumes of the cooling water flow and sampled source water per day in survey period *i*. Survival over one day is therefore $1 - PE_i$, and survival over the number of days (*d*) that the larvae are susceptible to entrainment is $(1 - PE_i)^d$. The studies are usually conducted over one year with surveys monthly. Therefore, the

[1] Statewide Water Quality Control Policy on the Use of Coastal and Estuarine Waters For Power Plant Cooling. Adopted October 10, 2010 by State of California Water Resources Control Board.
[2] Draft Amendment to the Water Quality Control Plan for Ocean Waters of California Addressing Desalination Facility Intakes, Brine Discharges, and to Incorporate Other Nonsubstantive Changes. Released July 3, 2014. Available at: http://www.waterboards.ca.gov/water_issues/programs/ocean/desalination/.

estimates of PE_i for each taxon of fish larvae from each survey are assumed to be representative of the cohort of larvae vulnerable to entrainment during the survey period.

While it is typically very easy to obtain a reasonably accurate estimate of the volume of the intake flow, estimating the extent and volume of the source water is more difficult with the approach dependent on the location of the intake. The entire area subject to entrainment over the entire period of time that the larvae for a species may be subject to entrainment is referred to as the Source Water Body (SWB), while, as shown in Equation 1, the PE is often calculated for a smaller portion of the source water, termed the Sampled SWB. The volume of the SWB may be fixed for intakes located inside enclosed embayments, or vary among survey periods for intakes on the open coast which are subject to changes in the speed and direction of ocean currents.

The other important component of the ETM is an estimate of the period of time that the taxon being analyzed is in the plankton and exposed to entrainment. This period of time is typically estimated using length data from the larvae measured from the entrainment samples for each taxon. Estimates of the maximum length and hatch length are estimated from the length data and the period of exposure to entrainment estimated by dividing the difference between the lengths by an estimated larval growth rate usually obtained from the scientific literature. The estimates of PE and period of exposure are combined in the ETM to provide an estimate of the proportional mortality (P_M) to the population due to entrainment as follows:

$$P_M = 1 - \sum_{i=1}^{n} f_i (1 - PE_i)^d, \qquad (2)$$

where f_i = the fraction of the source water population from the year present during survey i of n (usually monthly), and d = the period of exposure in days that the larvae are exposed to entrainment mortality represented by the PE_i.

The estimates of PE_i in Equation 2 would apply to an entire SWB such as a bay or lagoon, but in many studies it is impossible to sample over the total SWB. Therefore, Equation 2 is modified with the term P_S representing the proportion of the Sampled SWB to the total SWB containing the population of inference as follows:

$$P_M = 1 - \sum_{i=1}^{n} f_i (1 - P_S PE_i)^d, \qquad (3)$$

The proportion of the Sampled SWB to the total SWB (P_S) can be computed very simply for projects with intakes along long stretches of straight coastline by using the value of d for a taxon and determining the net alongshore transport over that period using data on coastal currents. The estimate of P_S is then calculated as follows:

$$P_S = \frac{L_G}{L_P}, \qquad (4)$$

where L_G = alongshore length of the sampling area, and L_P = length of alongshore transport over d days, the number of days the larvae for a taxon are susceptible to entrainment.

Assumptions associated with the estimation of P_M include the following:

1. The samples from each survey period represent a new and independent cohort of larvae;
2. The estimates of larval abundance for each survey represent a proportion of total annual larval production during that survey;
3. The conditional probability of entrainment, PE_i, is constant within survey periods;

4. The conditional probability of entrainment, PE_i, is constant within each of the size classes of larvae present during each survey period;
5. The concentrations of larvae in the sampled source water are representative of the concentrations in the extrapolated source water; and
6. Lengths and applied growth rates of larvae accurately estimate larval duration.

Area of Production Foregone (APF)

The APF (or alternatively, Habitat Production Foregone HPF) is the approach that has been used by California resource agencies in recent assessments of ocean intakes for power plants and desalination facilities to determine the appropriate mitigation to compensate for losses resulting from entrainment. Although all of the applications of APF in California have used estimates of intake effects based on ETM, it is important to recognize that the results from the ETM should be evaluated separately from APF. When supported by a well-designed sampling program, the ETM is likely to be the best approach for assessing the environmental impact of entrainment effects. Therefore, when an estimate of P_M from a well designed ETM study is available, it is important to evaluate the ETM estimate of P_M to determine whether there is a need for compensatory mitigation. The ETM was developed by fisheries scientists (Boreman et al., 1978; MacCall et al., 1983) and provides the same type of information (P_M) used in managing fisheries. The estimates of P_M can be interpreted the same way as estimates of the effects of fishing mortality on a population and, similar to a fisheries context, can be interpreted relative to other sources of mortality. Another important consideration that only applies to the assessment of impact using the ETM estimate of P_M is that the mortality is occurring to the stock of larvae in the SWB, and not an adult population. Interpreted in this context, an estimate of annual P_M that is very low relative to other natural sources of larval mortality, or levels of natural variation in the population size from year to year, indicates that entrainment effects on that organism are not likely to be significant. In contrast to the estimate of P_M obtained by the ETM process, the APF process provides an estimate of the area of habitat necessary to compensate for entrainment losses. This estimate does not provide any information on whether an impact is significant and should be mitigated. The determination of significant impact should be provided through assessment of the ETM by resource managers. That assessment should be based on a well crafted policy that provides clear guidelines for resource managers on the manner by which significance is considered in the context of entrainment effects.

The uses of APF in California have all been based on a P_M estimate of the proportional entrainment loss to the source water population of larvae due to entrainment, typically calculated over a year. For open coastal areas, the SWB potentially affected by entrainment is typically estimated using data on ocean currents. For example, using a simple unidirectional average current speed of 10 cm/s (0.33 ft/s), water over a coastal distance of 8.6 km (5.4 mi) would flow past an intake over a 24 h period, and the distance would increase to 86 km (54 mi) for a fish with larvae that are exposed to entrainment for 10 d. The distance offshore for the source water is usually limited to the depth range of the fish being analyzed. An ETM estimate of P_M of 0.01 (1.0%) would be interpreted as a loss of one percent of the larval supply from the SWB along 86 km (54 mi) of shoreline out to the depth range of the adult.

Using the above example, the APF is calculated as the estimate of P_M of 0.01 (1.0%) times the area of coastal habitat. Assuming that the distance offshore in our above example is 3 km (1.9 mi), then the total SWB is 258 km^2 (25,800 ha [63,753 acres]). The APF needs to include an adjustment for the habitat within the SWB associated with the production of the fishes being analyzed. For example, if the fishes being analyzed were rockfishes that are associated with nearshore rocky reefs, then the rocky reef habitat within the SWB would need to be estimated. Assuming that rocky reef habitat occurs in 20% of the total source water habitat, and therefore occupies a total area of 52 km^2 (5160 ha [12,751 acres]), then the APF estimate would be calculated as follows:

$$APF = P_M \cdot Habitat\ Area = 0.01 \cdot 52\ km^2, \tag{5}$$

resulting in an estimate of 0.52 km^2 (52 ha [128 acres]). The APF is interpreted as the area of nearshore rocky reef habitat that would need to be created or restored to replace the production of larvae lost due to entrainment.

Although APF is relatively easy to understand and to calculate, there are several important concepts that are critical to the approach. First of all, it is important to understand that no habitat is lost or damaged through the process of entrainment; the APF is estimating the habitat necessary to be created or restored to compensate for the entrainment losses, not the impacts on any habitat. Therefore, it follows that the most appropriate use of APF is for fishes that are associated with a specific habitat type that can be restored. Habitats such as eelgrass beds, mudflats, and wetland marsh in enclosed embayments, and habitats such as kelp beds and rocky reefs on the open coast have been common targets of restoration efforts, and there are numerous fishes that are associated with each of these habitats.

Therefore, while it is usually not difficult to identify fish larvae from a study that would provide the necessary nexus to restoration efforts through the use of APF, there are groups of fish where this is problematic. For example, there is no habitat available for restoration that is directly associated with the fishes occupying the coastal waters along the sandy beaches of southern California. These fishes release eggs and larvae into the water column where they are subject to entrainment. The interpretation of the APF estimate for these fishes is less useful because it is just a restatement of the ETM estimate of P_M. Using the example above, the P_M of 0.01 (1.0%) represents a loss of 1.0% of the larvae from the total SWB of 258 km^2 (25,800 ha [63,753 acres]), or the loss of larvae from 2.6 km^2 (258 ha [637 acres]) of coastal waters. These two estimates do not provide any information that could be useful in determining how to replace the losses to the source water for these fishes.

Estimates of APF for coastal pelagic fishes can also be misleading since the SWB for these species can extend over large expanses of coastline. Even though the ETM estimates of P_M may be very small, say 1.0%, the resulting APF estimate may represent a large area, resulting in the impression that entrainment is having a large impact on the population. For example, if the SWB for the species with a P_M = 1.0%, extended over a coastal area of 300 square km (116 square mi), which is representative of many species from studies along the California coast, the resulting APF would equal 30 ha (74 acres), which could be interpreted as a large area of habitat even though the likelihood that the proportional loss to the larvae would affect the population is probably close to zero. Conversely, a P_M of 20.0% for a coastal species with restricted habitat requirements such as shallow rock reef habitat with an area of 10 ha (24.7 acres) could be more problematic than the previous example because of the restricted habitat for that species even though the APF estimate of 2 ha (4.9 acres) is much less than the APF estimate for the larger SWB. Therefore, contrary to Raimondi (2011) the context provided by APF can be misleading and potentially problematic. This is especially true if fishes with different habitat requirements are combined into an average APF as recommended by Raimondi (2011).

Restoration Scaling Using APF

Introduction

The ETM is the method that has been used in California over the past 20 years for assessing the impacts of ocean intakes on marine populations. The APF has been used to scale restoration projects based on the results of ETM for several projects described in the Final WateReuse Report. The ETM/APF approach has been used for five different projects in California, including the Poseidon Carlsbad Desalination Project. Although APF is not necessarily dependent on the results of ETM, the two methods have been linked together in its implementation on a project-by-project basis for many power plant facilities and subsequently were integrated into the Draft Desalination Amendment.

In principle, the APF is very similar to other scaling methods in that it seeks to equate larval losses with habitat equivalency in order to estimate the amount of habitat that would be required to produce the equivalent number of estimated larvae entrained. On this basis, APF is not necessarily dependent on the results of the ETM. In order to calculate APF, some estimate of the proportional loss of a source population, and an estimate of the area of the source population's extent is required. APF could be used with any impact assessment that provides this information. Although typically applied to source populations of larvae, the same approach and method could be used for adult populations when estimates of these parameters relating solely to the adult population are available.

Application of APF

Study Design and Sampling

The important considerations regarding the use of APF begin with the design of the sampling program for an ETM-based assessment. If the intake for the proposed facility is located in a harbor, estuary, or other semi-enclosed body of water then the sampling might be restricted to that water body. Additional sampling outside of the water body may be required if the source water is subject to tidal exchange that would result in turnover of the source waters within the larval duration of most fishes, which is approximately 30 days. For example, an ETM-based intake assessment of the South Bay Power Plant in the south part of San Diego Bay (Tenera, 2004), only sampled areas that were south of the Coronado Narrows, a constriction in the bay that limits exchange with waters in the outer portion of the bay. Other intake assessments in smaller water bodies have included sampling in the ocean water just outside of the embayment to account for coastal species that might be transported in and out of the embayment where they would be subject to entrainment due to tidal exchange (e.g., MBC and Tenera, 2008; MBC et al., 2008; Tenera, 2008). The ETM models were modified in these studies to account for two source water bodies: the embayment and the coastal ocean waters.

The most likely locations for desalination plant intakes would be along the coast. A preliminary assessment of the options for an intake location can help reduce the potential effects of entrainment. For example, the concentrations of larval fishes collected during intake assessments along open coastal sandy beach areas in southern California (e.g., Huntington Beach, El Segundo, and Scattergood generating stations) tend to be much lower than the concentrations found inside of embayments (e.g., Encina Power Station, and Haynes, and Alamitos generating stations) or in coastal areas where there are multiple habitat types (e.g., San Onofre Nuclear Generating Station) (**Figure 1**). Along open coastal sandy beach areas, the homogeneity of the habitat is likely to result in concentrations of larvae that are, on average, relatively uniform throughout the source water. This results in the daily *PE* estimates used in the ETM being equivalent to the volumetric ratio of the intake volume to the estimated daily source water volume. The use of the volumetric ratio as the estimate of *PE* in the ETM allows for modeling potential impacts to the populations of larvae in the source water using the range of larval durations for a group of representative species. The results from a volumetric model could be used as a preliminary assessment for larger projects or as the final assessment for smaller projects with low intake volumes.

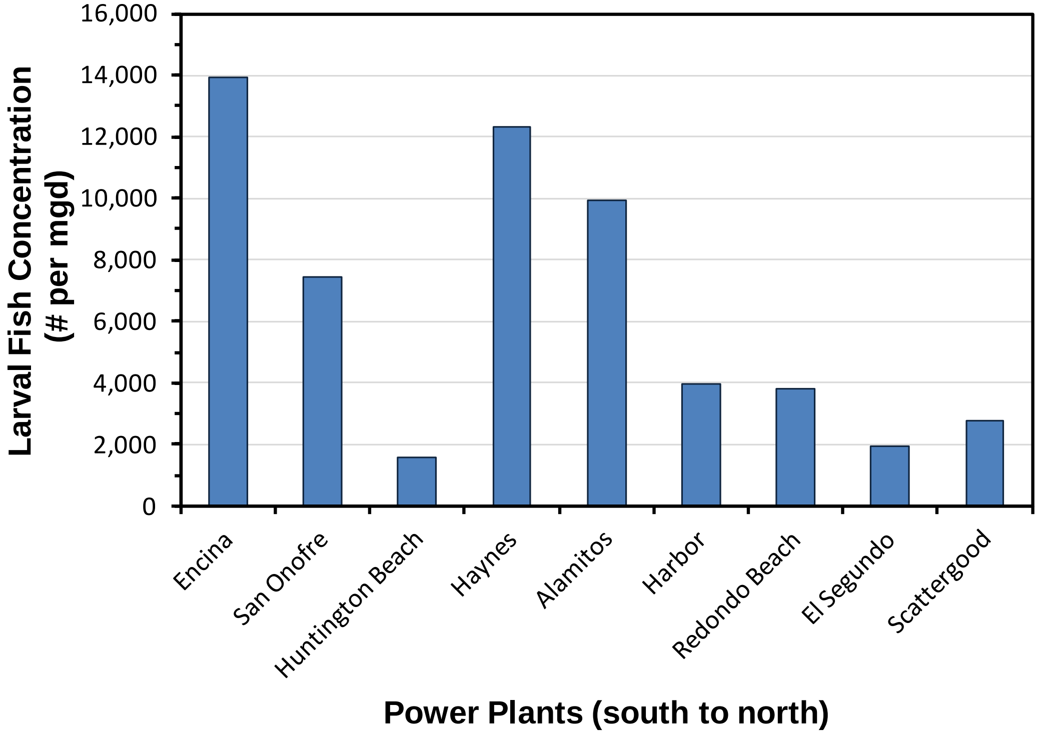

Figure 1. Concentrations of larval fishes from studies of power plant intakes in southern California. Data from Appendix E – Entrainment and Impingement Estimates (Steinbeck, July 2008) in Final Substitute Environmental Document for Water Quality Control Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling, May 4 2010.

Note: Encina = Encina Power Station, Aqua Hedionda Lagoon, Carlsbad; San Onofre = San Onofre Nulear Generating Station, San Clemente; Huntington Beach = Huntington Beach, Huntington Beach; Haynes = Haynes Generating Station, Long Beach; Alamitos = Alamitos Generating Station, Long Beach; Harbor = Harbor Generating Station, Los Angeles Harbor; Redondo Beach = Redondo Beach Generating Station, Redondo Beach; El Segundo = El Segundo Generating Station, El Segundo; Scattergood = Scattergood Generating Station, El Segundo.

The volumetric model is also applicable for providing an estimate of the impacts on other planktonic forms not specifically targeted by the intake assessment sampling. As discussed by Raimondi (2011) the ocean water used by power plants for cooling contains a much broader range of organisms than just the fish and shellfish larvae selected for assessment in these studies (**Figure 2**). Although a large majority of the organisms shown in **Figure 2** are not sampled during most intake assessments, the potential effects of entrainment on these populations can be estimated using a volumetric *PE*. The use of the volumetric approach is especially applicable to these other planktonic forms as they are generally distributed more uniformly in the coastal water than larval fishes, especially those fishes with strong habitat dependencies.

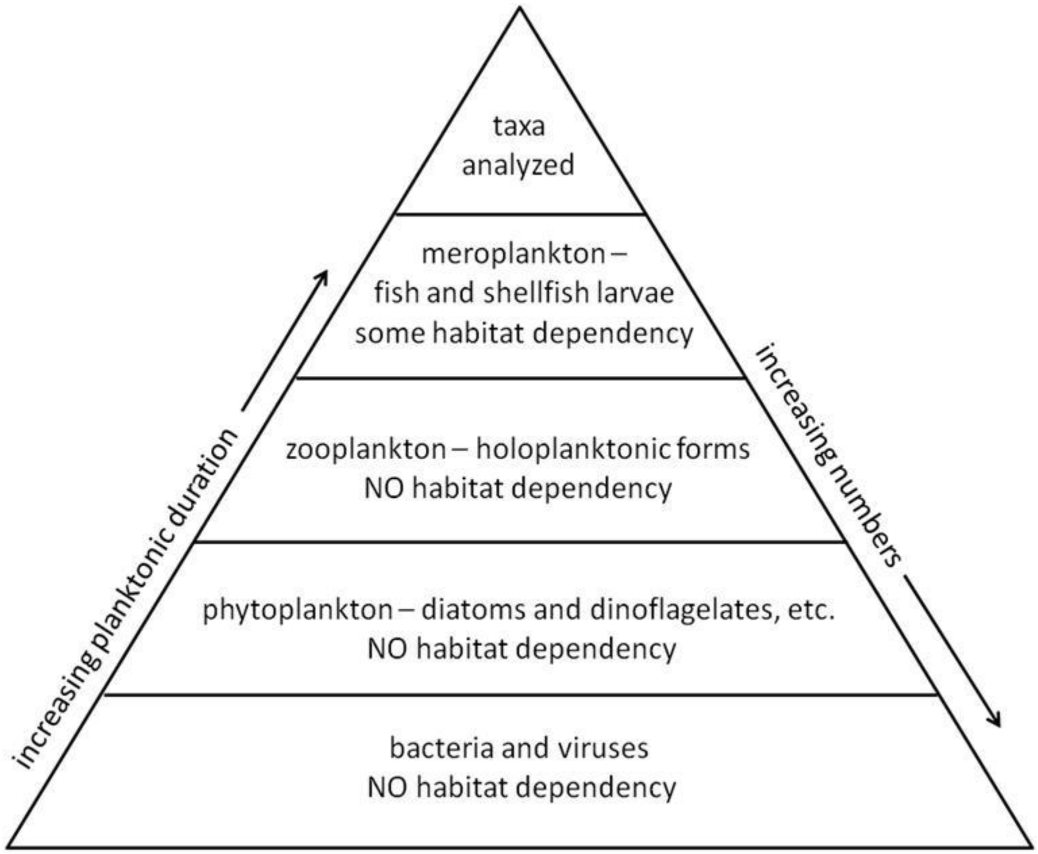

Figure 2. Representation of the types and relative abundances of plankton communities in the coastal oceans waters of California. The size of the area does not reflect the relative abundances of each planktonic form.

While a volumetric *PE* for ETM may be valuable for initial intake assessments in certain homogeneous habitats or for planktonic forms with no habitat dependency, the assumption that larval fish concentrations are uniform over large areas is not likely to be valid for many studies. This is especially true in coastal areas, such as areas with extensive rocky substrate, where there are a variety of habitats that support adult populations of different species of fishes. During reproduction, these habitat dependencies may become even more pronounced because some species use a specific habitat type for spawning, and some may even tend a nest of eggs associated with a specific habitat. Results of previous studies conducted in areas with a mix of habitats such as the Diablo Canyon Power Plant (DCPP) (Tenera, 2000) have shown that the distribution of larvae in an area can be strongly dependent on variation in habitat and water depths. These habitat dependencies can also occur in enclosed water bodies as shown in the study of the South Bay Power Plant in south San Diego Bay (Tenera, 2004), and, therefore, sampling should be designed to encompass all available habitats within the source water potentially subject to entrainment effects. Along the open coast, the sampling should be spread out to roughly the size of the area that larval fishes would be subject to entrainment over the course of a single day. This area of potential entrainment can be estimated using average current speeds. This approach is consistent with the concept of *PE*, which is the estimate of entrainment mortality within the sampled source water over a single day.

The recognition of the importance of habitat dependencies is one of the reasons for focusing these intake assessments on fish larvae. One of the important issues associated with these assessments is determining whether specific habitat types, and the associated species, are disproportionately affected by entrainment. Although no direct impacts on any fish populations have been shown to occur based on the results of any of the studies in California, it is conceivable that a small reef outcropping in an area could be disproportionately impacted by an intake located in close proximity. This would result in *PE* estimates for the fishes associated with this habitat that are much greater than the volumetric *PE* ratio, indicating that the fish larvae from this habitat are entrained at a higher rate and may be more susceptible to impacts.

Habitat dependencies are not an issue with many midwater and pelagic fishes such as anchovies, mackerel, barracuda, and some of the croakers. These fishes release eggs directly into the water column, which should result in relatively uniform dispersal of eggs and larvae through the source water. This relatively uniform dispersal was documented in the results of studies conducted in southern California (e.g., MBC and Tenera, 2005). In contrast with nearshore rocky reef fishes, which may have larvae that occur close to shore, the larvae of many midwater and pelagic fishes tend to be distributed over large areas of coastline thereby reducing the potential for intake effects.

There are also no habitat dependencies for almost all holoplankton, which make up the vast majority of the planktonic forms shown in **Figure 2**. Even in areas where the bottom habitat is not homogeneous, holoplankton would still, on average, tend to be distributed uniformly. Therefore, as mentioned previously, the volumetric *PE* ratio is a reasonable approximation for impacts to holoplankton and, in some cases, fishes and shellfishes larvae.

As a result of the strong habitat dependencies for many fishes, any preliminary intake assessment should include a survey of the habitats in the source water. This will require data on local ocean currents in order to estimate the potential area of source water potentially affected by entrainment. Larval durations of 10 and 30 days can be used to estimate the potential range of source water for the intake. In the early applications of the ETM in California, the source water volumes used to calculate *PE* were determined on the basis of average current speeds from both literature and from *in situ* instrumentation. Using these simple models, the SWB scales linearly with larval duration resulting in ETM estimates that vary largely due to differences in larval duration. Recent applications of the ETM have used pseudo-Lagrangian models based on empirical data on surface currents from high-frequency radar installations based on a technology referred to as CODAR (Coastal Ocean Dynamics Applications Radar) to derive particle tracks. These models allow for the incorporation of non-linear variation in the current patterns that determine the SWB. As a consequence, these ETM assessments likely provide more realistic models of larval dispersal. An ETM model utilizing multi-year CODAR data and a volumetric *PE* would provide an alternative approach for the assessment of projects.

While the ETM uses *PE* to estimate the daily mortality due to entrainment, the number of days that the larvae are exposed to entrainment can also be a critical component of the model when the scale of the SWB is restricted, and does not scale linearly with the number of days that larvae are exposed to entrainment. This scenario is most common when entrainment occurs in an enclosed or semi-enclosed water body. It can also occur on the open coast due to variations over space and time in ocean currents that occur due to retention zones behind headlands, or the occurrences of eddies and fronts. The actual implementation of the ETM incorporates terms to account for multiple sampling events and changes in the size of the source water, as well as the number of days the organisms are exposed to entrainment. The estimate of entrainment exposure is typically calculated based on the size of the fish larvae and estimates of larval growth rates published in the scientific literature. The estimates can vary considerably among different species of fishes, with estimates exceeding 30 or 40 days for some fish larvae. In the case of a restricted SWB, the proportional mortality will increase exponentially with the number of days as mortality rates are compounded. The reproductive capacity and population generation time for many holoplankton reduces the potential for impacts to these populations in situations where the SWB is restricted. This was recognized in the original USEPA guidance (USEPA 1977) for CWA §316(b) and provided the rationale for focusing intake assessments on fish and shellfish larvae.

As a result of the reduced potential for impact for most holoplankton, the use of the ETM estimates of intake effects based on data for fish and shellfish larvae will most likely result in conservative estimates of the potential effects of entrainment. As shown by Shanks (2009), the estimated dispersal distances based on oceanographic models similar to the approaches used in estimating SWBs for the ETM-based assessments conducted in California, consistently overestimated actual empirical measurements of dispersal for a wide variety of marine organisms with planktonic larvae (**Figure 3**). Shanks (2009) attributes this largely to larval behavior that is not incorporated into the dispersal models which results in many larvae with long larval durations having dispersal distances as short as species with larval durations of a few hours. This likely increases the conservative nature of the estimates using ETM. This is especially important when the results from the ETM are used in scaling mitigation to compensate for entrainment losses. Any mitigation using APF that is based on the results from ETM will likely provide a conservative estimate because the periods of exposure used in the model are likely overestimated for the target organisms.

Once the potential SWB is identified in the early planning stages, the habitats within that area can be determined. This determination will provide information on the species of fishes most likely to produce larvae that may be subject to entrainment, and will also determine if opportunities exist for the application of APF. As explained in Strange et al. (2012), an implicit assumption of APF requires that a fish population is limited by the availability of habitat. The initial assessment of the potential source water may not provide enough information to identify specific habitats that should be included in the sampling. In these cases, a sampling approach designed to provide representative data from the entire sampled source water subject to entrainment over a day is the best approach.

Selection of Species for Use with ETM/APF

The ETM estimates are typically only calculated for a limited number of taxonomic categories of larvae (taxa) for a study. This is partially due to the limitations of sampling organisms that have highly variable populations. In general, the numbers of larvae collected for most taxa are limited, reducing the options for analysis and especially the selection of appropriate targets for restoration scaling using APF. Therefore, it is important to thoroughly evaluate the species of fishes collected during the assessment sampling to determine if they are appropriate for ETM analysis, and potentially APF.

Ideally, it would be important to focus on fishes that could be most susceptible to entrainment effects, which unfortunately may be in lower abundance in the samples. When evaluating the choice on analyzing two species with annual entrainment estimates of 10 million larvae, the focus should be on the species with lower reproductive capacity (fecundity) and not on a species with high fecundity that has less potential for impacts.

The *PE* estimates from the ETM should be examined to determine if, on average, they are close to the volumetric ratio. If the *PE* estimates are close to the volumetric ratio they may be useful as a proxy for impacts to other species with similar habitat distributions and larval durations. Species with *PE* estimates that, on average, greatly exceed the volumetric ratio may indicate a species at risk of being impacted by entrainment losses. Alternatively, *PE* estimates below the volumetric ratio may indicate very low levels of entrainment mortality and subsequently, there is a lower risk of impact from entrainment losses. The other important issue to consider is the number of *PE* estimates calculated for a species. ETM estimates should not be calculated for species with only a few *PE* estimates (less than five or six *PE* estimates during a 12-month study).

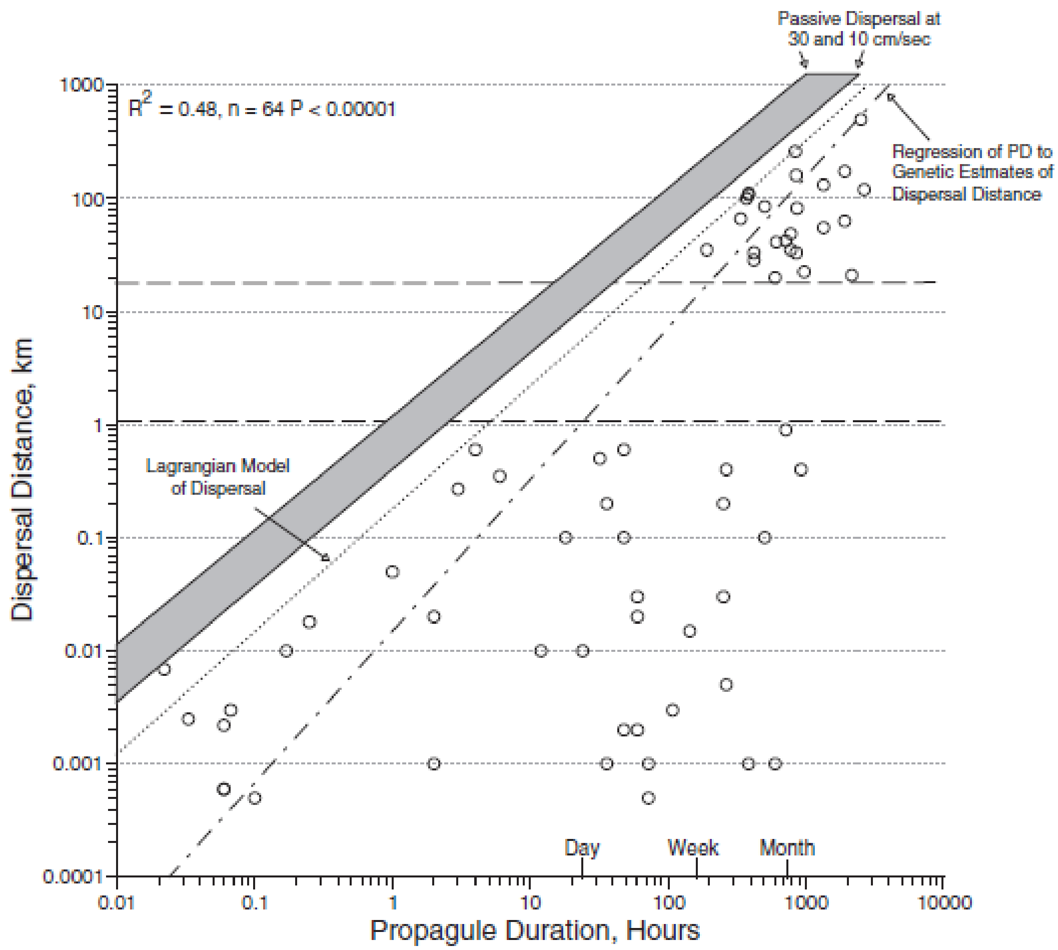

Figure 3. Figure from Shanks (2009) showing log/log plot of propagule duration (PD) in hours and dispersal distance in kilometers. Data are from Shanks (2009) and Shanks et al. (2003 as cited in Shanks [2009]). Plotted with the data points are (1) the distance propagules would be dispersed if they behaved as passive particles in a steady flow of 10 and 30 cm/s (gray shaded zone), (2) the distance passively drifting larvae would disperse as calculated using a Lagrangian model of dispersal (dotted line) (Siegel et al., 2003 cited in Shanks, 2009), and (3) dispersal distance estimated from a regression relating PD to dispersal distance calculated from genetic data (dot and dash line) (Siegel et al., 2003 cited in Shanks, 2009). Statistical results are from a correlation of the log/log data.

Considerations in evaluating the results of the ETM and which species to include in APF scaling relate directly to the quality of the data used in the ETM. Beyond the number of *PE* estimates available for a species, these considerations relate to the sampling design and the likelihood that the *PE* estimates provide unbiased estimates of actual entrainment effects. For example, intakes inside embayments likely entrain fish larvae from nearshore areas outside the embayment but it is unlikely that the source water sampling design provides an adequate characterization of the population at risk. As a result, APF scaling should focus on the species and habitats best characterized by the sampling.

These considerations are best shown using an example from the intake assessment completed for the DCPP (Tenera, 2000). The taxa of fish larvae included in the ETM analysis for the DCPP study were selected based on several criteria including their overall abundance in the entrainment sampling and their importance in recreational or commercial fisheries.

Applying the considerations on species selection to the data from the DCPP study, the first criterion for selecting taxa for inclusion in an APF scaling assessment should be the potential for entrainment to impact a species. This can be determined based on the estimate of the number of larvae entrained relative to the distribution of a species (**Table 1**). For example, Pacific sardine and northern anchovy were not included in APF calculations presented in Raimondi et al. (2005) because of the widespread distribution of these species, which reduces the likelihood that their adult populations could be affected by entrainment. This would be the same argument for excluding many holoplankton from APF. The levels of entrainment relative to the natural reproductive capacity for a species could also be used to determine whether to include a taxon in the APF scaling assessment on the basis of the potential for entrainment to impact a species. For example, the annual entrainment estimate for California halibut was approximately 14 million larvae, which is small relative to the potential annual reproductive output of a female California halibut that has been reported to be as high as 57 million eggs under laboratory conditions (Caddell et al., 1990). Because the estimated entrainment numbers are so small relative to the fecundity of the adults, it is highly unlikely that this species could be affected by entrainment.

The second criterion for selecting taxa for inclusion in an APF scaling assessment should be the consideration of habitat association, because adults of species with no direct habitat association may not benefit at all from restoration or will benefit indirectly, requiring an additional step to balance any restoration gains with entrainment losses. While ETM estimates were calculated for species such as Pacific sardine, northern anchovy, and California halibut, which do not have a strong habitat association, the majority of the fish larvae collected during the study were associated with shallow subtidal rocky reef habitat. Rocky reef habitat associated fishes were the logical focus of the APF analysis for the DCPP because they were the dominant taxa entrained and would benefit from habitat restoration. The nine taxa associated with this habitat were the focus of the initial APF analysis in Raimondi et al. (2005).

The third criterion for selecting taxa for inclusion in an APF scaling, should be an assessment of the underlying data used in the ETM estimate. Past assessments have included ETM results for taxa that may have only been collected during two or three surveys. As each survey represents a replicate measure of impact, two or three replicates is a very small sample size on which to base an assessment of either P_M or APF, greatly reducing the confidence in the estimate. For example, the results from the DCPP study show that the ETM estimate for cabezon was based on *PE* estimates from only four of twelve surveys (**Table 2**). This is a small number of samples and because there were other rocky reef associated fishes with a larger number of estimates, it would be reasonable to exclude cabezon from the APF scaling. It should also be noted that the ETM for sanddabs and California halibut was based on only three estimates of *PE*, another reason for not including these fishes in the assessment.

Table 1. Entrainment and ETM estimates for fish taxa included in DCPP intake assessment. Estimates are for study period from July 1997–June 1998. The area of rocky reef is based on an estimate from Raimondi et al. (2005).

Taxa Group	Estimated Annual Entrainment (millions of larvae)	Estimated Percent Entrainment Mortality for Source Population (P_M)	Estimated SWB (hectares)	Approximate Area of Rocky Reef (hectares)	APF Estimate (hectares)
Subtidal rocky reef associated fishes					
smoothhead sculpin	109	11.39	36,122	3803	
monkeyface prickleback	118	13.77	31,894	3358	
clinid kelpfishes	122	18.94	29,962	3155	597
blackeye goby	156	11.51	8560	901	103
cabezon	15	1.11	12,058	1269	
snubnose sculpin	75	14.94	31,737	3342	499
painted greenling	11	6.29	26,465	2786	175
KGB rockfish complex	208	3.88	20,149	2121	82
blue rockfish complex	7	0.41	14,146	1489	6
			Average APF (hectares)		244
Fishes with other habitat associations					
Pacific sardine	104	<0.01			
northern anchovy	106	<0.01			
white croaker	67	0.70			
sanddabs	6	1.03			
California halibut	14	0.47			

The fourth criterion for selecting taxa for inclusion in an APF scaling assessment involves consideration of the sampling design and the likelihood that the ETM estimate is providing an unbiased estimate of actual entrainment effects. For example, the intake at DCPP is located inside a shallow embayment that is open to nearshore coastal areas but is also surrounded by breakwaters and therefore protected from waves and strong currents. The sampling locations inside the intake cove were located in water depths of less than approximately 15 m (49 ft). The SWB was located along a rocky coastline with variable bathymetry that was also exposed to heavy wave action. Sampling in shallow water close to shore presented safety concerns and therefore the source water sampling was conducted in deeper water than the intake sampling. Due to the differences in sampling effort, there were many more larvae from fishes associated with shallow water rocky reef areas (e.g.,smoothhead sculpin and monkeyface prickleback) present in the intake samples compared to the source water samples. Because this discrepancy in the abundance of these two nearshore taxa could potentially bias the estimates of entrainment and APF, the results for smoothhead sculpin and monkeyface prickleback were not included in the final APF calculations shown in **Table 1**. The APF estimates for the six taxa of fish larvae shown in **Table 1** provide the best data for scaling potential mitigation projects to compensate for entrainment effects.

Table 2. Monthly estimates of *PE* and standard error (SE) and annual proportion of cabezon (*Scorpaenichthys marmoratus*) larvae in the *i*th survey period (*f*) and associated SE used in estimating ETM estimates of P_M for entrainment mortality for July 1997–June 1998 at DCPP.

Survey Date	PE_i	SE (PE_i)	f_i	SE (f_i)
Jul 21, 1997	0	0	0	0
Aug 25, 1997	0	0	0	0
Sep 29, 1997	0	0	0.00423	0.00319
Oct 20, 1997	0.1061	0.10281	0.00322	0.00289
Nov 17, 1997	0.0060	0.00340	0.04346	0.01365
Dec 10, 1997	0.0140	0.00395	0.08530	0.02190
Jan 22, 1998	0.0031	0.00244	0.49133	0.09834
Feb 26, 1998	0	0	0.16335	0.07329
Mar 18, 1998	0	0	0.20188	0.05692
Apr 15, 1998	0	0	0.00723	0.00460
May 18, 1998	0	0	0	0
Jun 8, 1998	0	0	0	0

APF Example Calculations

Huntington Beach Generating Station

The most problematic use of APF is for projects where the intake is located along a stretch of open coast that is largely composed of soft bottom habitat. The most abundant fish larvae at these locations are likely to be fishes classified as nearshore surf zone, and coastal pelagic species (Allen and Pondella, 2006). The fishes associated with these habitats generally release planktonic eggs or larvae into the water column. Due to the potential for greater natural mortality due to predation and other factors, these fishes also tend to have higher reproductive output than fishes in habitats that provide areas for fishes to lay eggs in nests that may be guarded by males or females of the species.

In contrast to projects located in habitats where there are opportunities to apply APF based on the species identified as being potentially impacted by a project, the approach for projects in open coastal soft-bottom habitats should be based on the identification of potential restoration opportunities. This was basically the approach used at the Huntington Beach Generating Station (HBGS), where an ongoing wetland restoration project was identified as the preferred mitigation option. Larvae from gobies that occupy mudflats in harbors and wetland areas were the most abundant fish larvae collected during the entrainment sampling at the HBGS (MBC and Tenera, 2005). These larvae were likely transported out of the wetland areas in the vicinity of the HBGS where they would be subject to entrainment. Gobies and the numerous species of flatfishes which would also benefit from the wetland restoration justified its use as a target for mitigation scaling.

The calculation of APF for CIQ gobies[3] involved recalculating the P_M estimate using ETM by including an estimate of the larval gobies in the estuarine habitats in the vicinity of the HBGS intake. The lengths of the CIQ goby larvae collected in the study were used to estimate that the larvae were subject to entrainment for a period of up to 34 days. This period of entrainment susceptibility is much longer than estimates of entrainment exposure from studies conducted in estuarine areas. This is likely due to the transport of gobies out of mudflats in estuarine areas, their normal habitat, into nearshore areas where they are transported along the coast until they are either transported into an area where they can settle and begin transformation into juvenile and adult stages, or they die due to various causes of mortality including starvation, predation, etc. Although the larval duration indicated that goby larvae could be transported a distance of up to 61 km, it was assumed that the larvae primarily came from the estuarine areas in the immediate vicinity of the HBGS. The large mudflat areas in the Los Angeles-Long Beach Harbor complex were not included in the estimates. The areas of open water and wetland habitat for Newport Bay, Santa Ana River/Talbert Marsh, and Anaheim Bay/Huntington Harbor were calculated using GIS and data collected from the National Wetlands Inventory (NWI) (Source: http://wetladsfws.er.usgs.gov).

The estimated areas from the NWI were used to calculate the numbers of goby larvae present in those areas using concentrations of goby larvae collected from Agua Hedionda Lagoon in San Diego County from June 2004 through May 2005 (Tenera, 2006). Average concentrations from monthly sampling at five stations in both shallow and deeper open water portions of the lagoon were adjusted to areal densities using the water depths at each of the stations. These areal densities were multiplied by the size of the three estuarine areas to provide a total estimate of larval gobies for each month. The monthly estimates were combined with the extrapolated nearshore source water estimates of goby larvae from the HBGS sampling for the corresponding months to recalculate the *PE* estimates used in the ETM calculations as follows:

$$PE_i = \frac{E_i}{N_i + W_i}, \qquad (21)$$

where E_i = number of larvae entrained per day during the i^{th} survey, N_i = number of larvae in the total nearshore source water per day during the i^{th} survey, and W_i = number of larvae in the wetland/estuarine areas per day during the i^{th} survey.

The revised ETM estimate for CIQ gobies was calculated using *PE* estimates that incorporated both nearshore and estuarine area larvae. The revised ETM estimate of 0.0090 (Std. Error = 0.6445) was not significantly reduced from the value of 0.0099 in the original HBGS intake assessment (MBC and Tenera, 2005) because the larvae in the estuarine areas only contributed a small fraction of the total number of larvae relative to the size of the extrapolated SWB. The conservative estimate of APF based on the estuarine areas was 12.4 ha (30.6 acres). A more accurate and lower, less conservative estimate could be obtained be reviewing the wetland classifications used by NWI and excluding the areas that did not represent adult goby habitat.

Although this estimate of APF provided a direct approach for scaling restoration for the effects of HBGS entrainment, the actual APF used in the scaling was based on fish taxa that generally had no strong association with any habitats in the source water. The wetland restoration could have been justified on the basis of the large entrainment estimates of larval gobies and also on the presence of larvae for many other

---

[3] CIQ gobies refers to a taxonomic grouping of gobies that cannot be identified to species as larvae. The three species are arrow goby ***C**levelandia ios*, cheekspot goby ***I**lypnus gilberti*, and shadow goby ***Q**uietula y-cauda*.

fishes that were associated with wetland habitat or this area during some stages of their life history. For example, a number of flatfish larvae, including California halibut, were identified in the entrainment samples; these species are known to use shallow wetland areas as nursery habitat.

The average *PE* estimate for goby larvae at HBGS (0.0023) was also very close to the volumetric ratio of 0.0021 indicating that the larvae were representative of daily entrainment mortality for a range of planktonic organisms. Furthermore, because the goby larvae are in nearshore habitats where there is no adult habitat for larval settlement, the estimated period of time that the larvae were exposed to entrainment was 34 days. This period was longer than the estimated periods of exposure for other fish taxa in the study that were mostly associated with coastal pelagic and soft-bottom habitats and are likely adapted to recruiting into the nearshore soft-bottom habitats characteristic off the area around HBGS. This resulted in an ETM estimate of P_M that was higher than any of the other nearshore taxa of fishes analyzed and therefore represented the most conservative estimate of entrainment effects and the resulting APF.

Diablo Canyon Power Plant

Two example estimates of APF are available for the DCPP. The original approach taken for calculating APF estimates for DCPP was presented in recommendations to the Central Coast Regional Water Quality Control Board by a group of scientist advisors (Raimondi et al., 2005). The APF estimates in the report were calculated using the average ETM estimate of proportional mortality (P_M) and SWB estimates from nine fish taxa to derive a single APF estimate for all of the taxa rather than calculating an average of the APF estimates. The two approaches result in different estimates. The correct approach, used in later applications of APF, is to calculate APF separately for each taxon because the P_M and SWB are based on data from a number of different sources making comparisons among taxa difficult, whereas the final APF integrate the estimates into a common currency that can be averaged under certain conditions.

The APF estimate in Raimondi et al. (2005) was calculated from data for nine of the larval fish taxa collected during the study that as adults are all associated with nearshore rocky reef habitat. The APF calculations were based on the estimated rocky reef habitat in the SWB for those nine fish taxa. A subsequent study (Raimondi, 2011) estimated APF based on the same data but included twelve taxa of fish in the calculations, the original nine fish taxa with adults that were associated with nearshore rocky reef habitat, and also white croaker, sanddabs, and California halibut that are not associated with rocky reef habitat. The calculations in Raimondi (2011) also used the entire SWB in the APF calculations, rather than just the areas of habitat associated with adults of the species used in the APF estimate. This resulted in a substantially larger estimate (2000–2400 hectares) in Raimondi (2011) than the 120–400 ha APF estimate from Raimondi et al. (2005).

Issues with the approach presented in Raimondi (2011) include the following:

- Use of the entire SWB in the APF calculation,
- Combining species with different habitat associations, and
- Implying that APF can be applied as a general estimate of impacts across species.

The use of the entire SWB for the APF calculations in Raimondi (2011) is problematic for fishes with specific habitat associations because the SWB will likely include large areas of habitat that are not suitable for supporting the adult population. Therefore, if the goal of APF is to estimate the area of habitat necessary to replace larval production lost due to entrainment then it is paramount that the calculations use the actual area associated with larval production for a taxon.

The use of the entire SWB in APF calculations in Raimondi (2011) and in application of the methodology for the HBGS and the Poseidon Carlsbad Desalination Project also deviates from the original concept of

APF presented in Raimondi et al. (2005) and Steinbeck et al. (2007). The issue with using the entire SWB in APF calculations is best demonstrated by an example using a small, one hectare (ha) (2.47 acres), rocky reef area that is located along a large expanse of sand beach. The reef may be in reasonably close proximity to the location of an intake that results in entrainment of larvae from a species with adults that are closely associated with the rocky reef habitat and are not found in the adjoining sand habitat. Using the approach in Raimondi (2011), an ETM estimate of P_M of 1.0 % for that species would be applied to the entire SWB, even though the source water habitat is only one ha (2.47 acres). If data on ocean currents from the study indicated a total SWB of 1000 ha (2,470 acres), the resulting APF would equal 10 ha (24.7 acres), or ten times the size of the actual source habitat for the species. Clearly, the results using this approach are not representative of the impacts on this species and should not be used in estimating impacts on other organisms.

The example in the previous paragraph demonstrates one potential use of APF in the interpretation of P_M. The extrapolations of source water bodies outside of the sampled area in ETM include the implicit assumption that the proportion of different habitats in that SWB is uniform. Properly applied, the APF adjusts these results to correct for the actual area of habitat in the source water for a species. There is no adjustment when the entire SWB is used in the calculations. The abundance and distribution of fish larvae in the source water must be linked to the types of habitat and the distribution of habitat to properly interpret both the ETM and APF. These factors affect the underlying biological data used in the ETM and vary by species, especially when the species are associated with different habitats. The approach in Raimondi (2011) ignores these important factors and the critical role of APF in correctly interpreting the results of the ETM. Combining estimates across species makes the interpretation of APF impossible unless all of the species are associated with a single habitat type. As indicated by Raimondi (2011) the actual impacts of entrainment on a species can only be interpreted correctly using APF, but it is only useful when applied correctly.

Raimondi (2011) also states that the results of ETM models can be applied across species, and contrasts ETM with demographic modeling approaches, such as AEL, that would apply only to the species being modeled. Applying the results of ETM across species should only be done when the data meet very specific conditions and would usually be limited to a small number of species—certainly not all species. An exception is cases where the PE estimates fit a volumetric model which would apply across all species and planktonic forms. Even when the volumetric approach is valid, the results of the ETM will still vary among species due to differences in larval durations and seasonal variation in currents that result in variable source water estimates. The important difference between the ETM and the demographic models is not that the results can be used as a proxy for other species, it is the fact that the ETM can be calculated for any species given the availability of reasonable data. The ETM is driven by the data collected during a study, while demographic modeling techniques will always be limited to species with available life history data, which may not be available for the species collected during an assessment study. Therefore, ETM has a strong empirical basis, which is usually not the case for demographic models.

The argument in Raimondi (2011) for averaging APF estimates across fishes with widely disparate habitat requirements is based on the assumption that individual APFs represent replicate estimates of the impact on the source water. This would be true if the selected taxa were unbiased, independent samples from the population of all possible entrained taxa and therefore are a representative sample of the true model parameters. The fishes analyzed in these studies were selected based on numerous criteria that would not result in a set of unbiased samples.

The concept of averaging APF estimates in order to scale a restoration project has been further expanded in Raimondi (2011) to use the multiple APF estimates to calculate estimates of the error associated with the average APF. These estimates are then used to calculate confidence intervals that are used to set the required mitigation at a level that would ensure full compensation for any entrainment losses. As mentioned previously, the APF estimates must be independent, unbiased samples from the population for which an inference is being made. This population would include all possible estimates of APF based on all possible taxa affected by entrainment. The APF estimates cannot be treated as data or replicates because they are model estimates that are based on a complex set of underlying data that are different for each taxon. The data for each taxon will depend on the SWBs, the times of the year that the larvae for that fish taxon are present in the source water and entrainment samples, and the period of time that the larvae are subject to entrainment. The same underlying data are also used for many of the taxa removing any chance that the individual estimates are independent replicates of impact. In fact, a proper evaluation of the underlying correlation structure among the estimates would be extremely complicated. Therefore, as recognized by Raimondi (2011), the data from such estimates are unlikely to satisfy any of the conditions necessary for treating the data using standard statistical distributions. Although, this is treated using a resampling approach by Raimondi (2011), the underlying problems with using the APF estimates as replicates go far beyond the simple statistical distribution of the estimates.

Although there is no basis for treating the APF estimates as statistical replicates, the APF does scale the ETM into equivalent habitat units for individual species, which could be averaged under the condition that similar habitat is associated with the suite of species being averaged. For the reasons mentioned above, this average APF should be viewed skeptically because of the potential range of APF values that are due to differences in seasonal occurrence and differences in larval duration among species. Despite these problems, the average APF could be useful as a heuristic tool to inform policy decisions on restoration.

The issues with the approach in Raimondi (2011) is further complicated when there are multiple species included in the assessment that all have different habitat associations. For example, the application of APF for the Poseidon Carlsbad Desalination Project was based on an average for three species which all had different habitat associations. Due to the different habitat associations, the larvae for these fishes were all collected in highest abundance in different locations within a SWB that was clearly delineated into separate regions. Therefore, using the entire SWB for the APF calculations resulted in estimates for each species that were much larger than the actual habitat necessary to compensate for the loss of larvae. Also, the distribution of the larvae in the SWB resulted in ETM estimates that when averaged, were unlikely to be representative of losses to other species.

Summary and Discussion

Compensatory mitigation programs used to address the effects of IM&E at ocean intakes can be broadly defined into two approaches: fish hatcheries and stocking, and habitat creations, restoration or enhancement. The use of fish stocking for mitigating the effects of IM&E has fallen out of favor with the state and federal resource agencies overseeing these projects; habitat enhancement projects are now preferred. For example, the recently released Draft Desalination Amendment for desalination plant intakes indicates that habitat restoration is the preferred approach for mitigating any effects of desalination plant operations.

Broadly, any compensatory mitigation program involves the following steps:

1. Estimating impacts;
2. Identifying potential restoration project options;
3. Scaling restoration project options to impacts;
4. Project selection and implementation; and
5. Monitoring and administration.

Although each of these steps includes numerous decisions and requires information sources and data, all of the habitat restoration or enhancement projects reviewed in the Final WateReuse Report provide examples of best practices that could be used in developing a recommended approach for providing mitigation for desalination plant intakes. For example, all of the habitat restoration or enhancement projects described in the Final WateReuse Report had robust studies that were used to identify the potential impacts associated with the operation of the intake system.

Many of the recent ocean intake assessment in California have used an ETM-based assessment and then used APF to determine the appropriate scale of restoration to mitigate for the losses. The projects were designed largely to compensate for the effects of entrainment. The approach taken for these projects has been to fully compensate for all losses without any consideration of the significance of the larval losses to adult populations. This is a recent development since earlier studies have included evaluations of whether entrainment losses translated into significant population level effects. For example, the independent MRC working on the mitigation for the San Onofre Nuclear Generating Station (SONGS) recognized that production from any restoration project needed to replace the losses to midwater fish populations due to entrainment. The estimates of the losses varied from zero, if complete compensation occurred for the loss of 4–5 billion larvae, to a maximum production of 1200 MT (1320 ton) (MRC, 1989). The final mitigation of 60 ha (150 acres) of wetlands for losses to midwater fishes recognized that a substantial level of compensation occurred in the population. Similarly, the restoration associated with the Salem Nuclear Generating Station (SNGS) on Delaware Bay in New Jersey included a conversion of entrainment and impingement losses to actual biomass production from restored wetlands.

Although dependent on the quality of the impact assessment data, providing a well defined approach for scaling mitigation projects is probably the most difficult and also the most important task. There are several problems with the approaches used in California. The difficulty of trying to scale impacts to nearshore fishes, such as croakers, that are not associated with habitats that can be targeted for restoration is shown in the SONGS project, which used a more *ad hoc* approach to scaling, and in the project for the HBGS, which was based on APF scaling. The problems with the use of APF are related to having data on impacts to fishes that can be associated with specific habitats. While a project such as the Poseidon Carlsbad Desalination Project used APF, the scaling was affected by combining fishes from various habitats. The best opportunity for the use of APF is in coastal embayments where fishes associated with wetlands would be the target of restoration efforts and also along the open coast (e.g., DCPP) where fishes associated with shallow rocky reef would be the target of restoration efforts. Despite the issues identified in the example from the DCPP, which were due to the fact that this was the first application of APF, the type of data and approach used to document the impacts and habitat provide a model that could be used for other projects.

Entrainment is the primary concern for desalination intake assessment, as screening technology allows for the minimization of impingement effects. One of the most critical decisions that must be addressed prior to implementing a restoration project is the selection of the method used to scale the estimates of the intake losses or impacts. One of the criteria for project selection is a strong nexus between the impacts and the selected project. The strength of this nexus is largely dependent on the selection of a scaling method, and the ability of the method to provide a strong connection between the restoration and the entrainment losses. Providing this connection affects stakeholder acceptance of the mitigation project and also affects the process for evaluating the success of a project.

Unlike the potential effects of desalination plant intakes, the scaling used in NRDA is normally applied to an environmental accident and needs to address the direct, adverse environmental impacts to habitats and any associated populations. In the case of NRDA, the resulting mitigation scaling would need to consider the composition and demographics of the affected habitat, populations or both, and include consideration of the time period between the loss of services from the resources and the start of the restoration project (French McCay et al., 2003b). In the case of an IM&E compensatory mitigation program for a desalination plant, there are no direct, adverse impacts to habitats due to IM&E. The small intake volumes for most facilities would likely result in larval losses that would have no effect on the source water populations of the affected species.

In California, where most of the ocean desalination plants are likely to be located, the issue of adverse impacts on these source populations has been removed as a consideration in the Draft Desalination Amendment. The proposed amendment calls for compensation or replacement for all losses due to the construction and operation of a desalination plant, including all "intake-related marine life mortality." Therefore, the goal of the IM&E scaling process for desalination plants in California would be to provide a connection between the larval losses and the preferred restoration project.

The scaling process for entrainment is simplified by having the goal of replacing only the larval production lost due to entrainment. Therefore the required replacement applies to a specific set of species that in turn require a specific habitat type to support their population. The success of habitat restoration as applied to the effects of an oil spill under the NRDA process for example, needs to consider many trophic levels as well as the species-specific responses within each trophic level (Peterson and Lipcius, 2003). In this respect, linking restoration to ecological function is greatly complicated by the extent of impacts. The scaling and monitoring process requires greater breadth and complexity in order to provide insight into the project's nexus to impact and subsequently to its successful implementation. This process is simplified in the case of scaling entrainment losses.

Preservation and restoration of marine habitat is the preference of regulators in the recent Draft Desalination Amendment and in the recently adopted policy for the use of coastal waters for power plant cooling. This philosophy is consistent with conservation biologists who express a strong preference for preserving or restoring habitat based on the recognition that habitat destruction and degradation are responsible for the majority of losses to biological communities (Soule, 1986). In addition, restoration projects that benefit habitat will contribute to the welfare of several species simultaneously. A project that focused on enhancing the larval production through stocking new recruits of a target species is likely to fail to achieve a sustainable increase in the population if habitat is not available to support the additional recruits (Meffe and Carroll, 1997).

The scaling approach chosen is often closely related to the manner by which an impact has been assessed. The total number of larvae entrained (usually expressed as the annual average) is the most basic measure of entrainment impacts and has been used for many impact assessments conducted outside of California. This approach to impact assessment then relates annual entrainment to habitat restoration using an estimate of production. Obtaining a realistic estimate of average annual entrainment is very difficult in practice. The reason an accurate estimate of average annual entrainment is difficult to obtain is that larval population sizes vary greatly within and between years. Factors that determine the size of the larval population within and between years include seasonal spawning characteristic, adult population size, and many other factors. Some of these factors act directly on the larval population (e.g., the availability of food or the number of predators) and some of these factors act indirectly on the larval population (e.g., by affecting the abundance of reproductive adults through changes in ocean climate). From one year to the next, larval abundance can vary by orders of magnitude and the causes of this variation can be very difficult or impossible to determine. Because the absolute annual entrainment varies directly with the size of the local larval population, many years of data are likely to be required to gain a meaningful estimate of average annual entrainment that will be reflective of the true annual entrainment likely to occur during the operational lifetime of an intake. For some species, their abundance varies on decadal scales (e.g., sardines and anchovies [Chavez et al., 2003]), and therefore multi-decadal data collection would be required to assess this fully. Alternative methods have been developed, such as ETM and APF that seek to provide a more robust approach to estimating impact and subsequent restoration scaling.

As discussed in Strange et al. (2012), HEA is an appropriate description of a scaling technique that considers the provision of equivalent ecological services following the loss of a habitat or habitats. REA is the most appropriate description of a scaling technique that considers the provision of an equivalent resource following the loss of some similar resource. The goal of both HEA and REA is to provide an equivalency between losses and gains, and therefore both are best understood as variations of the more generic scaling method, EA. APF also seeks to equate losses due to entrainment with gains due to habitat restoration. While not a necessity, APF normally does this by estimating habitat equivalencies using empirical data collected and analyzed as part of the ETM. Differences between APF and EA, such as those discussed by Strange et al. (2012), are actually differences in implementation that are rooted in the separate, historical developments and applications of the two methods. All three approaches (HEA, REA, and APF as described by Strange et al. [2012]) attempt to balance the losses incurred due to the impact with the gains accrued through restoration.

Two important distinctions between the ETM/APF approach and the manner of implementation of HEA and REA as described in Strange et al. (2012) are worth considering carefully. The first is the use of published values of productivity in the scientific literature to scale losses and gains in the HEA and REA approach described in Strange et al. (2012). This productivity is used to scale absolute entrainment values to equate the entrainment estimates with habitat. The reason for relying on published productivity values to scale habitat most likely originated as a method for scaling restoration to impacts from environmental accidents such as those considered under the NRDA process. Because restoration planning following an environmental accident is generally reactionary (i.e., taking place after the impact has occurred), deriving an empirical baseline is only possible if a specific study already exists to support the local productivity estimates. In contrast, ETM and APF arose within the planning environment, when projects seeking to gain permits are required to assess their potential impacts. The timeline of these projects allows, in most cases, for empirical studies to obtain estimates of abundance and extent, which in turn provide proxy estimates of habitat productivity rather than relying on published information that may not be accurate for local conditions.

This contrast between APF and other methods is shown in the example application of HEA in Strange et al. (2012). The authors use an estimate of the production of gobies from Allen (1982) to calculate the necessary habitat required to compensate for entrainment losses at the HBGS. Ignoring their error in using adult production to estimate larval production which dramatically increases the estimated habitat necessary to compensate for the entrainment losses, the HEA scaling is based on a single estimate of production from the literature. There is no way to determine how representative this estimate would be for a project at a different location that may continue to operate for many years. This application of HEA contrasts with the strong empirical basis for the APF estimate for gobies from the study, which was based on data collected over a year in the source waters in the vicinity of the HBGS.

Empirical data could be collected to provide estimates of local habitat productivity, although within and between year variation in estimates may require that several years of data be collected to provide an accurate estimate, particularly as these estimates are important to the assumptions of the restoration program. If the estimates are incorrect, there is a significant risk that the restoration project may either overestimate the habitat requirements resulting in a project scale that is too large, underestimate the habitat requirements resulting in significant challenges to the implementation of an adaptive management approach, or potentially fail to meet the conditions of the permit.

A more significant consideration when comparing and contrasting the HEA and REA methods described in Strange et al. (2012) with the ETM and APF approach to scaling is the matter of absolute estimates (HEA/REA as described in Strange et al. [2012]) versus proportional estimates (ETM-based APF) of entrainment. The amount of habitat or numbers of organisms affected by a one-time event such as an oil spill are easier to quantify than a long-term impact such as entrainment, because entrainment occurs over the period of intake operation, which can be as long as 50 years. The absolute numbers of larvae entrained will change considerably within and between years due to numerous physical and biological factors that affect levels of larval production and survival. This is why it is critical to have an assessment method such as the ETM for entrainment that provides a relative measure of impact integrated across a year that should vary much less over time than the absolute levels of impact that would be the basis for scaling using HEA and REA as described in Strange et al. (2012). Similarly, the APF estimate resulting from ETM for an individual species should also be relatively invariant over time, because while the larval production from an area of habitat within the SWB will vary considerably over time, the proportion of the larvae in the source water produced by that area of habitat should be much less variable.

A more fundamental concern is also highlighted in these simple examples of HEA, and that is the principle of balancing gains with losses. Losses are generally finite. In the case of a habitat that has been damaged by a single event such as an oil spill, the habitat may be able to recover at some point. If not, under CERCLA and OPA legislation, that habitat should be restored or replaced. In both cases the losses are finite. However undiscounted gains are infinite, because the creation or enhancement of additional habitat to offset interim losses will usually not have a finite point in time when they will cease to contribute resource services. By discounting gains over time, the resource provisioning provided by the enhanced or created habitat will decline in value over time (the annual decline is 3% under NOAA guidance). The compounding nature of the decline means that for the first few years the resources continue to provision at a similar rate, but as they age the rate of decline increases to a point that provisioning become essentially negligible. However it is important to note that it does not end but converges asymptotically towards zero.

Other scaling techniques such as food chain transfer models and demographic modeling approaches require extensive background data to implement and these data may only be available for taxa and groups that have been extensively studied. Typically this would include commercially or recreationally fished species such as American lobster on the Atlantic Coast of North America (French and McCay et al., 2013a) or well studied ecosystems such as the wetlands of the Delaware Estuary that were restored as part of the SNGS compensatory mitigation program known as the EEP.

The availability of data still requires careful consideration of the reliability of these models to address the aims of the restoration program. It is plausible that even the very best models will fail to account for important variables simply because environmental variation is notoriously hard to predict. Furthermore, sophisticated models that are capable of making accurate predictions may result in a restoration project that is scaled sufficiently to demonstrate compliance with the program objectives. However, these models can be very hard for many stakeholders to grasp at the planning stage. This may isolate stakeholder groups that feel they are unable to contribute to important decisions on the scale of the restoration project. In turn this may result in difficulties in the earlier planning and decision making processes, delay project decisions, and ultimately affect project success. On this basis, models that require many parameters laden with assumptions and technical detail are not as desirable as models that rely primarily on empirical data to inform the outcomes of the scaling process, such as ETM/APF

Concluding Remarks

These examples should make it clear that the use and application of APF should be carefully considered. As discussed by Strange et al. (2012), there are habitats and species to which APF should not be applied, although in most studies there are species collected that could provide a basis for APF-based restoration. For example, the most abundant fish larvae collected during the HBGS study were goby larvae. Even though the sampling for the HBGS study was done in the nearshore coastal areas along a sandy beach, there are several small wetland areas that export gobies into the nearshore where they are subject to entrainment. Although the use of the goby data provided a reasonable alternative for restoration scaling, the decision was made to use an average APF from a suite of fishes that had no habitat dependency or had variable habitat dependency. The original APF estimate for gobies of 12.4 ha (30.6 acres) was probably comparable to the 80 ha (198 acres) estimate from the coastal fishes when you take into account the increased productivity of wetland compared to nearshore sandy habitat. Considering that the focus of the final restoration was the same wetland areas used in the goby APF estimate, the approach using gobies was much more reasonable. This example is especially problematic when you consider that the applicant was required to base the restoration on the 80 ha (198 acres) estimate and was not allowed to adjust the mitigation ratio for the increased productivity of the wetland habitat because it was considered out-of-kind restoration, even though an in-kind alternative was available.

While the calculation of APF is relatively simple, the correct application of the methodology requires considerable site-specific data, insight into the sampling design used to collect the data and the biology of the organisms collected. Other scaling methods such as HEA and REA require considerable knowledge and research to identify population estimates and estimates of production that can be used in the calculations. The results of the recent assessments of ocean intakes in California have provided ETM results that could be used to calculate estimates of APF. Unfortunately, as the previous examples demonstrate, the correct application of APF is more complicated than multiplying the estimates of P_M and a SWB.

The historical precedent in California for using ETM to assess the impacts of intakes and APF to scale restoration projects for power plants led to the integration of this approach in the recently released SWRCB Draft Desalination Amendment addressing desalination. The arguments for favoring ETM/APF over other approaches are universal and are not unique to California. On this basis, the precedent set by the state of California implies that significant consideration should be given to the application of ETM/APF for assessing intake effects and scaling restoration accordingly for any desalination development, regardless of the regional setting of the policy framework and environment affected.

The success and widespread use of APF for scaling restoration projects will require that a consistent approach to its use be adopted, and especially that a method be developed for scaling larval production in open coastal waters into other coastal habitat. Although the APF in this case would result in habitat area that is not equivalent to open coastal waters, the use of out-of-kind mitigation is usually acceptable when it results in creation of habitat with greater ecological value.

Habitat restoration as compensatory mitigation for IM&E impacts from desalination intakes in coastal and estuarine environments is a viable solution to addressing the sustainable implementation of large scale coastal desalination. Compensatory mitigation for environmental effects is an established field in many other areas of environmental development planning, the most notable of which is the regulation of power plant intakes under CWA §316(b). As with all project planning activities, early consideration of environmental factors will ensure that implementation progresses smoothly and will increase the likelihood of success. This early consideration should include the identification of goals and objectives as well as the incorporation of stakeholder issues that should continue throughout the process. Objective scaling requires a quantitative approach, and relative approaches such as the ETM/APF are likely to be the most robust scaling methods to apply to IM&E effects because of the highly variable nature of marine populations, particularly planktonic populations subject to entrainment effects.

Literature Cited

Allen, L.G. Seasonal abundance, composition, and productivity of the littoral fish assemblages in upper Newport Bay, California; *Fishery Bulletin* **1982,** 80:769-790.

Allen, L. G.; Pondella, D. J. Surf zone, coastal pelagic zone, and harbors. pages 149–166 in *The Ecology of Marine Fishes: California and Adjacent Waters*. L. G. Allen, D. J. Pondella, and M. H. Horn (eds.); University of California Press: Berkeley, CA, 2006.

Boreman, J.; Goodyear, C. P.; Christensen, S. W. *An empirical transport model for evaluating entrainment of aquatic organism by power plants*. US Fish Wildlife Service, FWS/OBS–78/90: Ann Arbor, MI, 1978.

Boreman, J.; Goodyear, C. P.; Christensen, S. W. An empirical methodology for estimating entrainment losses at power plants sited on estuaries. *Transactions of the American Fishery Society* **1981,** 110, 253-260.

Chavez, F.P.; Ryan, J.; Lluch-Cota, S.E.; Niguen, M.C. From Anchovies to Sardine and Back: Multidecadal Change in the Pacific Ocean. *Science* **2003**, 299, 217-221.

French McCay D.P.; Peterson, C.H.; DeAlteris, J.T.; Catena, J. Restoration that targets function as opposed to structure: the feasibility of replacing lost bivalve production and filtration. *Marine Ecology Progress Series* **2003a** 264:197–212.

French McCay D.P.; Gibson M.; Cobb, JS. Scaling restoration of American lobsters: combined demographic and discounting model for an exploited species. *Marine Ecology Progress Series* **2003b,** 264, 177–196.

MBC Applied Environmental Sciences (MBC) and Tenera Environmental, Inc (Tenera). *Final Report. AES Huntington Beach LLC Generating Station Entrainment and Impingement Study*; prepared for AES Huntington Beach, LLC: Huntington Beach, California. 2005.

MBC and Tenera. Alamitos Generating Station Clean Water Act Section 316(b) impingement mortality and entrainment characterization study. Prepared for AES Alamitos L.L.C., Long Beach, CA. 2008.

MBC, Tenera, and URS Corp. Haynes Generating Station Clean Water Act Section 316(b) impingement mortality and entrainment characterization study. Prepared for City of Los Angeles Dept. of Water and Power, Los Angeles, CA. 2008.

MacCall, A. D.; Parker, K. R.; Leithiser R.; Jessee, B. Power plant impact assessment: A simple fishery production model approach. *Fishery Bulletin* **1983,** 81, 613-619.

MRC. *Final Technical Report of the Marine Review Committee to the California Coastal Commission H. Mitigation*; prepared by R. F. Ambrose. MRC Document No.89-2045, 1989. available at http://marinemitigation.msi.ucsb.edu/documents/MRC_reports/index.html.

Meffe, G.K.; Carroll, G.R. *Principles of Conservation Biology*, 2nd edition. Sinauer: Sunderland, MA, 1997.

Peterson, C. H.; Lipcius, R. N. Conceptual progress towards predicting quantitative ecosystem benefits of ecological restorations. *Marine Ecology Progress Series* **2003,** 264, 297-307.

Raimondi, P., G. Cailliet, and M. Foster. Diablo Canyon Power Plant Independent Scientists' Recommendations to the Regional Board Regarding Mitigation for Cooling Water Impacts. Submitted to Central Coast Regional Water Quality Control Board. Available at: http://www.swrcb.ca.gov/rwqcb3/water_issues/programs/diablo_canyon/index.shtml. 2005.

Raimondi, P. *Variation in entrainment impact estimation based on different measures of acceptable uncertainty*; California Energy Commission, PIER Energy-Related Environmental Research Program; CEC-500-2011-020, 2011.

Ricker, W. E. Computation and interpretation of biological statistics of fish populations. *Journal Fisheries Research Board Canada* **1975,** Bulletin 191, 382 pp.

Siegel, D. A., B. P. Kinlan, B. Gaylord, and S. D. Gaines. Lagrangian descriptions of marine larval dispersion. Marine Ecology Progress Series 2003, 260:83-96.

Shanks, A. L. Pelagic larval duration and dispersal distance revisited. Biological Bulletin 2009, 216:373-385.

Soule, M. (ed). *Conservation Biology*. Sinauer Publishing: Sunderland, MA, 1986.

Steinbeck, J. R.; Hedgepeth, J., Raimondi, P.; Cailliet, G.; Mayer, D. L. *Assessing power plant cooling water intake system entrainment impacts*. Report to California Energy Commission; CEC-700-2007-010, 2007.

Steinbeck, J. R. Compilation of California Coastal Power Plant Entrainment and Impingement Estimates for California State Water Resources Control Board Staff Draft Issue Paper on Once-through Cooling. In “Final Substitute Environmental Document for Water Quality Control Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling”, July 8, 2010.

Strange, E. M.; Allen, D.; Mills, D.; Cacela, D.; Donavan, C.; Lipton, J.. *Compensation for Cooling Water Intake Entrainment Effects and the Habitat Production Foregone Method.* The California Energy Commission, PIER Energy Related Environmental Research Program; CEC-500-2013-114, 2012.

Tenera. *Diablo Canyon Power Plant. 316(b) Demonstration Report*. Document No. E9-055.0; prepared for Pacific Gas & Electric Co.: San Francisco, CA. 2000.

Tenera. South Bay Power Plant cooling water system effects on San Diego Bay, Volume II: Compliance with Section 316(b) of the Clean Water Act for the South Bay Power Plant. Prepared for Duke Energy South Bay LLC, Chula Vista, CA. 2004.

Tenera. Cabrillo Power I LLC, Encina Power Station Clean Water Act Section 316(b) impingement mortality and entrainment characterization study. Effects on the biological resources of Agua Hedionda Lagoon and the nearshore ocean environment. Prepared for Cabrillo Power I LLC, Carlsbad, CA. 2008.

United States Environmental Protection Agency (USEPA). *Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: Section 316(b);* P.L. 92-500. 1977.