Energy Research and Development Division
FINAL PROJECT REPORT

COMPENSATION FOR COOLING WATER INTAKE ENTRAINMENT EFFECTS AND THE HABITAT PRODUCTION FOREGONE METHOD

Prepared for: California Energy Commission
Prepared by: Stratus Consulting Inc.

APRIL 2012
CEC-500-2013-114

PREPARED BY:

Primary Author(s):
Elizabeth Strange

Stratus Consulting Inc.

Contract Number: 500-04-025

Prepared for:

California Energy Commission

Joe O'Hagan
Contract Manager

Linda Spiegel
Office Manager
Energy Generation Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Compensation for Cooling Water Intake Entrainment Effects and the Habitat Production Foregone Method is one of three final reports for California Energy Commission Agreement Number 500-04-025, San Jose State University Foundation Account No. 22-1509-3550-Stratus, conducted by Stratus Consulting Inc. The information from this project contributes to the Water Intake Structure Environmental Research (WISER) program and the Energy Research and Development Division's Energy-Related Environmental Research Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

A significant portion of California's generating capacity is represented by power plants sited along the state's coast, bays, and estuaries that use once-through cooling technology. This cooling technology requires the diversion of large volumes of water into the power plant where this water is passed by the condenser to capture waste heat and then discharged. Millions of small aquatic organisms such as fish eggs and larvae that are present in the water are also carried into the power plant, where they are subjected to thermal, physical, or chemical stresses. This process is called entrainment and can significantly impact local populations of fish, crabs, and other species.

Regulatory agencies often require power plant operators to restore degraded wetland habitats to compensate for these entrainment effects. The amount of restoration that is required is based upon a quantitative technique that balances losses from entrainment with the gains expected from a proposed restoration. This study considered key ecological issues in determining the type, scaling (amount), and cost of habitat restoration needed to offset losses of estuarine and marine fishes due to entrainment by power plant cooling water intake structures.

This study showed that the habitat production foregone method could be reliable for estimating the extent of restoration needed in bay and estuary settings. However, the estimates were unreliable when used for power plants located on the open coast. Additionally, restoration scaling results could be made more reliable by using more comprehensive methods to determine predicted fish losses that consider entrainment, recruitment, and biomass production rates. This study demonstrated that comparisons could determine whether restoration or prevention technologies such as cylindrical wedgewire screens for cooling water intakes were more cost-effective for minimizing entrainment losses when reliable estimates of the extent and cost of restoration were available.

Keywords: California, entrainment, cooling water intake, habitat production foregone, restoration scaling, empirical transport model

Please use the following citation for this report:

Strange, Elizabeth M., David Allen, David Mills, Dave Cacela, Colleen Donavan, and Joshua Lipton. 2012. *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.

TABLE OF CONTENTS

PREFACE ..... **i**

ABSTRACT ..... **ii**

TABLE OF CONTENTS ..... **iii**

LIST OF FIGURES ..... **v**

LIST OF TABLES ..... **v**

Executive Summary **1**

Introduction 1

Project Purpose 1

Project Results 2

Project Benefits 3

CHAPTER 1: Introduction **4**

1.1 Background and Overview 4

1.2 Purpose 6

1.3 Project Objectives 6

1.4 Report Organization 6

CHAPTER 2: Project Approach **8**

CHAPTER 3: Project Outcomes **9**

3.1 Background on Restoration Scaling 9

3.1.1 Origins 9

3.1.2 Goal of Restoration Scaling 9

3.1.3 Habitat Equivalency Analysis (HEA) 9

3.1.4 Value Equivalency Analysis (VEA) 9

3.1.5 Resource Equivalency Analysis (REA) 9

3.2 The HPF Scaling Method 10

3.2.1 HPF as HEA 10

3.2.2 The HPF as REA 11

3.3 Evaluation of HPF Assumptions 11

3.3.1 Assumption of Habitat Limitation 11
3.3.2 Standing Stock Compared to Rate of Fish Production 12
3.3.3 Definition of the Source Water Area (SWA) 12
3.3.4 Interpretation of Proportional Mortality (PM) 13
3.3.5 Habitat Equivalency 13
3.3.6 Scaling Based on Averages 15
3.3.7 Discounting 17
3.4 Evaluation of HPF Analyses 18
3.4.1 Moss Landing Power Plant 18
3.4.2 Morro Bay Power Plant 25
3.4.3 Diablo Canyon Power Plant 25
3.4.4 Huntington Beach Generating Station 26
3.4.5 Summary of Omissions, Biases, and Uncertainties in HPF Analyses 28
3.5 HPF Alternatives 29
3.5.1 Alternative Scaling Approach 29
3.5.2 Developing Estimates of Fish Production 31
3.5.3 Restoration Monitoring and Adaptive Management 37
3.5.4 Guidelines for Restoration Scaling 38
3.5.5 Recommended Elements of a Restoration Proposal 38
3.5.6 Scaling Alternatives When Species Are Not Habitat-Limited 38
3.6 Use of Restoration Costs in Cost-Effectiveness and Cost-Benefit Analyses 39
3.6.1 Cost-Effectiveness Analysis 39
3.6.2 Cost-Benefit Analyses 39
CHAPTER 4: Conclusions 42
4.1 Recommendations 43
4.2 Benefits to California 43
References 47
Glossary 44

Appendix A: Restoration Actions and Restoration Costs A-1

LIST OF FIGURES

Figure 1: The relationship between the size of SWA and the size of the replacement habitat (A_r) under different hypothetical scenarios in which values are varied for the habitat quality of the replacement habitat before (q_b) and after restoration (q_r) relative to that of the SWA (q_i). 15

Figure 2: Production flows to nekton from net annual marsh primary production 35

LIST OF TABLES

Table 1: Hypothetical example illustrating variation in average PMs resulting from differences in the estimated size of the source areas used in the averaging 16

Table 2:. Alternative HPF estimates of the scale of restoration using the different averaging scenarios provided in Table 1 16

Table 3: Summary of results of HPF analyses for four coastal power plants in California 20

Table 4: Summary of analysis of HPF assumptions for the MLPP, MBPP, DCPP, and HBGS 24

Table 5: Summary of omissions, biases, and uncertainties in HPF scaling 29

Table 6: Estimates from the published literature of rates of secondary production in coastal habitats (in grams dry weight per square meter per year, g dw m^{-2} yr^{-1}) 37

EXECUTIVE SUMMARY

Introduction

A significant number of California's power plants that are sited along the state's coast, bays, and estuaries use once-through cooling technology. This technology requires the diversion of huge amounts of water from the ocean, bay or estuary into the power plant's cooling system. These diverted water volumes can total from the tens to hundreds of millions of gallons per day. In the power plant the diverted water is passed once by the condenser to remove waste heat and then is discharged. Millions of small aquatic organisms such as fish eggs and larvae that are carried along in this diverted water are often killed from thermal, physical, or chemical stresses as they pass through the power plant; this impact is called entrainment.

Power plant operators are required to assess and, if appropriate, mitigate or compensate for the ecological losses from these entrainment impacts. Habitat compensation or restoration is commonly required by permitting agencies to replace entrainment losses since even the best technology available cannot eliminate all entrainment impacts.

Restoration scaling is the term for determining how much restoration is needed to offset entrainment losses, taking into account increased productivity from the restoration. Scaling as used here refers to incorporating both the time and area considerations into restoration needs. There are different approaches to quantifying entrainment losses and restoration needs. In California, an approach used in some power plant cases is the habitat production foregone method that estimates the amount of restoration needed by applying the proportional mortality of larvae due to entrainment to the waterbody area that is the source of the larvae entrained, known as the source water area.

Project Purpose

This goal of this study was to review the habitat production foregone method in the context of restoration scaling to determine the advantages and disadvantages of this approach for different applications and to recommend guidelines for the use of this approach to restoration scaling.

Specific project objectives included:

- Evaluating the habitat production foregone method in the context of restoration scaling.
- Recommending ways to improve the data and methods used for estimating the restoration needed to offset entrainment losses.
- Discussing the use of restoration costs in cost-effectiveness analysis.
- Identifying the information needed to develop comprehensive estimates of restoration costs.
- Providing information on restoration actions to benefit California species vulnerable to entrainment.

Project Results

The project's key findings and recommendations were:

- The habitat production foregone method could provide a reasonable estimate of the entrainable larvae within a well-defined source water area when demographic data was limited. However, this was only true for enclosed or semi-enclosed water bodies where the extent of the source water area and larval populations could be reliably determined, when larval density was a suitable proxy for recruitment or productivity, and when the source water area included habitats that were the same type and quality as proposed restoration sites.
- The habitat production foregone method could be improved by explicitly considering measures of recruitment, growth, and survival in the types of habitat targeted for restoration. Measures of recruitment and productivity were useful for estimating the amount of restoration and were among the most useful metrics for monitoring restoration success.
- The habitat production foregone method estimates were too uncertain and unreliable to be useful for evaluating power plants on open coasts, even with extensive analysis of ocean currents and potential larval dispersal.
- Restoration scaling could provide more reliable estimates by explicitly balancing the gain in fish needed to offset a given entrainment loss using measures of recruitment (the addition of new recruits to the population per unit of time) or productivity (the rate of biomass production per unit of time). The most accurate scaling required an estimate of the amount of increase (the rate of change) in fish numbers or biomass caused by restoration from either enhanced production or preservation of existing production against foreseeable loss whenever possible.
- Restoration scaling offered an advantage over the habitat production foregone method by accounting for the time elements of losses and gains and expressed those losses and gains in terms of present value equivalents.
- Restoration costs could be compared to the costs of prevention technologies to determine the most cost-effective way to minimize entrainment losses when reliable estimates of the amount and cost of restoration were available. An appendix to the report supported such a cost-effectiveness analysis by providing information on restoration actions to benefit particular species and the information needed to develop comprehensive restoration costs.
- It was imperative that restoration scaling was rigorous when practical and that practitioners used or developed the necessary ecological data. Permitting conditions may not achieve the goal of resource protection if the scale and costs of restoration were underestimated. The same metrics should be used for restoration scaling and monitoring and adaptive management of restoration activities should be conducted to improve the likelihood that restoration goals are met.

- Targeted restoration monitoring should be used to fill data gaps and greatly improved a practitioners' ability to reliably scale restoration projects to offset entrainment losses, predict the restoration's ecological benefit, and monitor restoration success.

Project Benefits

The information in this report could benefit California regulators, facility operators, environmental stakeholders, and the California Energy Commission. Guidelines on the appropriate uses of the habitat production foregone method were provided, as well as suggestions for improving the data and methods used for estimating the restoration needed to offset fish losses from power plants and desalination plants co-located with power plants. Information on using restoration costs for comparing the costs to permit applicants of implementing technology was also provided. This information could minimize costs to the public and mitigate losses absent the technology, which is directly relevant to licensing and permitting decisions about cost-effectiveness.

CHAPTER 1: Introduction

1.1 Background and Overview

Ecological restoration is increasingly recognized as one of the most important ways to protect natural resources from degradation and species loss as a result of human activities. The CALFED Program, for example, has spent nearly a half billion dollars in the past three years alone on habitat restoration actions to help restore the ecological health of the San Francisco Bay/Delta ecosystem. This report uses the term *restoration* to mean *restoring, rehabilitating, replacing,* or *acquiring the equivalent of* the habitat needed to offset entrainment losses of aquatic organisms, with a focus on fish species.[1]

Restoration can be particularly important when human activities that are necessary to promote human welfare harm ecological resources in ways that cannot always be prevented. For example, in some cases even the best technology available (BTA) cannot eliminate all environmental injuries that may result from power plant construction and operation, and permitting agencies may seek habitat restoration to offset injuries that may continue to occur even after technology implementation.

The use of cooling water intake structures by California's coastal power plants is a prominent example of a technical feature of power plant operation that may include residual impacts even after application of BTA. For the past several years, the U.S. Environmental Protection Agency (U.S. EPA) has been developing regulations to minimize the adverse environmental impacts of cooling water intake structures, pursuant to Section 316(b) of the federal Clean Water Act (CWA) (33 U.S.C. §1326). The State of California Water Quality Control Board and associated regional boards implement Section 316(b) under the federal National Pollutant Discharge Elimination System (NPDES) program. The California Energy Commission (Energy Commission) has authority for certifying any new or expanded facility with greater than 50 megawatt (MW) capacity, pursuant to the 1974 Warren-Alquist Act (Public Resources Code Section 25000 et seq.). When these plants are in the coastal zone, the California Coastal Commission (CCC) has an important role in the review of repowering projects. The Energy Commission must abide by CCC decisions unless they are infeasible or would result in greater harm to the environment.

---

[1] This definition of *restoration* follows its use in the natural resource damage assessment process, which is the origin of restoration scaling (NOAA 1997). It is comparable to the term *mitigation* as defined under Section 404 of the Clean Water Act, where "compensatory mitigation" refers to the "restoration, establishment, enhancement, or in certain circumstances preservation of wetlands, streams or other aquatic resources for the purpose of offsetting unavoidable adverse impacts" (www.epa.gov/wetlandsmitigation).

Section 316(b) of the federal CWA provides that:

> Any standard established pursuant to Section 1311 [CWA §301] or Section 1316 [CWA §306] and applicable to a point source shall require that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact.

The U.S. EPA has interpreted Section 316(b) to mean that "adverse aquatic environmental impacts occur whenever there will be entrainment or impingement damage as a result of the operation of a specific cooling water intake structure" (U.S. EPA 1977). As a cooling water intake structure withdraws water from local water bodies, organisms in the water column are trapped against intake screens (impingement) or drawn into the power plant's cooling system (entrainment), resulting in losses of billions of organisms each year, mostly the eggs, larvae, and juveniles of estuarine and marine fishes.

Despite the development of a number of mitigation technologies, such as screens across the openings of intake pipes, it has proven impossible to eliminate all of the organism losses that may occur as a result of intake structure operation. In particular, there are currently few technologies or operational measures for effectively reducing entrainment (U.S. EPA 2004a). As a result, habitat restoration has been considered as a means to offset unavoidable losses.

At the federal level, courts have ruled that restoration is not a technology for the purpose of determining BTA under Section 316(b). At the state level, however, restoration may still play a role to offset residual losses because both the California Coastal Act (CCA) and the California Environmental Quality Act (CEQA) include provisions for restoration as a means of protecting California's natural resources:

- The CCA requires that marine resources be maintained, enhanced, and, where feasible, restored (Section 30230), and that the biological productivity and the quality of coastal waters, streams, wetlands, estuaries, and lakes be maintained and, where feasible, restored (Section 30231).
- CEQA considers a variety of measures, including avoiding impacts; minimizing impacts; rectifying the impact by repairing, rehabilitating, or restoring the impacted environment; reducing or eliminating the impact by preservation and maintenance; and compensating for the impact by replacing or providing substitute resources or environments.

Thus, irrespective of national Section 316(b) regulations, California licensing and permitting agencies may continue to require restoration as a means to offset impingement and entrainment losses that may continue to occur even after implementation of BTA. Furthermore, the cost of sufficient restoration to offset entrainment and impingement that would occur with different technology alternatives can be an important element in evaluating which technology to require at a given facility, where different alternatives may fit within the definition of BTA.

Because of the continued importance of restoration in this and other contexts, California will need reliable methods to quantify the production of organisms in restored habitats, both to estimate the amount of restoration needed to offset losses and to determine restoration success.

1.2 Purpose

The purpose of this report is to review a method known as Habitat Production Foregone (HPF) or Area Production Foregone (APF) in the context of restoration scaling. The HPF is used in California to estimate the amount of restoration needed to offset entrainment losses at coastal power plants. Restoration scaling originated as part of the natural resource damage assessment (NRDA) process, and is a method for determining the amount of harm caused by a given environmental impact, the amount of benefit resulting from a restoration action, and the proportionality between the two measurements. *Scale* refers to both spatial and temporal extent. In the simplest terms, scaling can be thought of as a type of accounting method used to balance past and future losses with past and future gains (Allen et al. 2005a).

1.3 Project Objectives

The overall objective of this project was to consider key ecological issues in determining the type, amount, and cost of restoration needed to offset losses of estuarine and marine fishes due to entrainment by power plant cooling water intake structures.

Specific objectives were to:

- Evaluate the HPF method in the context of restoration scaling.
- Recommend ways to improve the data and methods used for restoration scaling to offset entrainment losses.
- Discuss the use of restoration costs in cost-effectiveness analysis.
- Identify the information needed to develop comprehensive estimates of restoration costs.
- Provide information on restoration actions that may benefit California species vulnerable to entrainment.

1.4 Report Organization

This report provides an overview of the HPF method in the context of restoration scaling. This review of the HPF method includes an in-depth discussion of specific assumptions of the HPF method, an evaluation of HPF analyses conducted to date, and suggestions for developing more reliable data and improving methods used to determine the amount of restoration needed to offset a given magnitude of entrainment. This material is followed by a discussion of the use of restoration costs for cost-effectiveness analysis. The report includes an attachment that provides suggestions for restoration actions for particular species and information needed to develop comprehensive restoration cost estimates. This material is organized into the following sections:

- Section 2 outlines the project approach.

- Section 3 discusses project outcomes, including background on restoration scaling (Section 3.1); a description of the HPF method (Section 3.2); an evaluation of the main assumptions of the HPF (Section 3.3); a review of HPF studies (Section 3.4); recommendations for data and methods to improve restoration estimates (Section 3.5); and the use of restoration costs for cost-effectiveness evaluations (Section 3.6).
- Section 4 provides conclusions and recommendations for how the Energy Commission can use project results to conduct restoration scaling, evaluate restoration proposals, and increase the likelihood of successful restoration actions.
- Appendix A provides information and resources regarding restoration actions to benefit particular species, as well as the information needed to develop comprehensive restoration costs.

CHAPTER 2:
Project Approach

Documents on the HPF were assembled and reviewed for appropriateness of assumptions, data, methods, and interpretation of results. There is no single document that provides a comprehensive description of the HPF method. This review considered information found in parts of several documents and presentations, including: Duke Energy (2000); CCRWQCB (2004); CEC (2005); Foster (2005); Raimondi et al. (2005); Appendix C of York and Foster (2005); Raimondi (2005, 2006a, 2006b); Davis et al. (2006a, 2006b); Steinbeck (2006a, 2006b); and Steinbeck et al. (2007).

The research team also reviewed individual HPF analyses for four California power plants (Moss Landing, Morro Bay, Diablo Canyon, and Huntington Beach) to assess the basis for and validity of their restoration estimates. The entrainment studies and modeling results underlying the HPF analyses were also reviewed: Diablo Canyon (Tenera 2000a); Moss Landing (Tenera 2000b); Morro Bay (Tenera 2001); and Huntington Beach (MBC Applied Environmental Sciences and Tenera Environmental 2005). Also considered were relevant Energy Commission decisions, facility compliance documents, and other unpublished reports. This information was analyzed by reference to the scientific literature on restoration scaling.

In addition, the research team reviewed relevant portions of recent analyses of the environmental implications of once-through cooling by the Energy Commission (York and Foster 2005), fisheries scientists with experience in conducting entrainment studies and HPF analyses (Steinbeck et al. 2007), and the Electric Power Research Institute (EPRI 2007).

To identify species-specific restoration actions, local biologists were contacted for their recommendations about restoration activities that could benefit the species of concern and examined the relevant published and unpublished documents on the ecology of the species. For restoration costing information, the team contacted local restoration experts for estimates of costs associated with planning, implementing, and monitoring restoration. All sources are cited in the main report, with complete citations for all referenced documents provided in the reference list at the end of the report.

CHAPTER 3:
Project Outcomes

3.1 Background on Restoration Scaling

3.1.1 Origins

Restoration scaling was developed in the context of natural resource damage assessment (NRDA). NRDA was developed to assist in the assessment of economic damages resulting from natural resource injuries that are difficult to value in monetary terms. The use of ecological metrics for restoration scaling makes it possible to express value (preferences and tradeoffs) in terms of an ecological, rather than a monetary, currency of exchange (Freeman 1993; Kopp and Smith 1993; NOAA 1997; Ofiara 2002).

3.1.2 Goal of Restoration Scaling

Restoration scaling begins by expressing losses and gains in equivalent units, and then establishes a scaling equation with losses on one side and restoration gains on the other. The scaling exercise adjusts the amount of restoration until the equation balances future gains with past (and ongoing) losses (NOAA 1997; Ofiara 2002; Allen et al. 2005a).

The following sections describe the categories of scaling techniques that have been devised to evaluate equivalence among restoration losses and gains.

3.1.3 Habitat Equivalency Analysis (HEA)

If the injury is to habitat, and it is possible to measure both the area of habitat lost and the area of habitat needed to offset the loss, then HEA is an appropriate scaling technique. In practice, most HEAs involve the measurement of one or more natural resource "services" in a process known as *service-to-service scaling*. The National Oceanic and Atmospheric Administration (NOAA 2006) has distinguished two types of services: human use services, which are those services that natural resources provide to people (for example, surface waters provide drinking water); and ecological services, the services that one natural resource provides another natural resource (for example, wetlands provide nursery habitat for fish) (Allen et al. 2005a).

3.1.4 Value Equivalency Analysis (VEA)

A VEA involves v*alue-to-value scaling*, which focuses on the value (that is, benefits or satisfaction) that people derive from natural resources, where values can be compared or measured without conversion to dollars. A VEA is useful when it is not possible to restore exactly the same services as those lost, but it is appropriate to scale restoration based on equally valued alternative services (Allen et al. 2005a; Lazo et al. 2005).

3.1.5 Resource Equivalency Analysis (REA)

When the number of organisms (or other resource unit) lost and gained can be measured, resource-to-resource scaling using a REA is the most appropriate technique. Here, the primary challenge is to differentiate organism losses and gains through time from fluctuations in

biological populations that result from other factors such as natural environmental variation, immigration, emigration, interactions among species, and other ecological constraints (Allen et al. 2005a).

3.2 The HPF Scaling Method

The Habitat Production Foregone (HPF) scaling method combines elements of both HEA and REA.

3.2.1 HPF as HEA

The first step in an HPF analysis seeks to represent entrainment losses in terms of habitat area. This is accomplished by conducting source water sampling of larvae and using an entrainment assessment method known as the *Empirical Transport Model* (ETM) to estimate the proportional mortality (PM) of larvae in the source water area (SWA) due to entrainment (Steinbeck et al. 2007).[2] By multiplying the SWA by the PM, the area within the SWA containing the quantity of larvae entrained (the so-called HPF or area production foregone) is determined as follows:

$$A = PM \times SWA \qquad \text{(Equation 1)}$$

where:

> A is the estimated area containing the quantity of larvae entrained (that is, the HPF estimate).

For example, if the PM is 25 percent (that is, 25 percent of the larval population in the SWA is entrained) and the SWA is 2,000 acres, then the HPF assumes that 25percent of 2,000 acres is the amount of habitat represented by the entrainment loss. In this example, the estimate is 500 acres.

The following data from the ETM are required to implement the HPF method using the PM:

- Total number of larvae entrained (parameter E in the ETM).
- Larval density and abundance in the affected area (parameters ρ and N in the ETM).
- Proportion of sampled source water to total source water (parameter P_s in the ETM).

Of these various inputs, only the total number of larvae entrained can be measured directly with relatively minimal uncertainty and without ecological assumptions.[3]

---

[2]. The ETM method described in Steinbeck et al. (2007) is based on a model originally developed by Boreman et al. (1978, 1981) for Hudson River entrainment studies and later modified by MacCall et al. (1983) for power plants located on estuaries and open coasts. A similar model was developed by Barnthouse et al. (1979) to address impingement. Because local biologists consider California impingement losses to be insignificant, the HPF only evaluates entrainment losses.

[3] Uncertainty is sometimes addressed by estimating a range in the estimated amount of replacement habitat.

It is also difficult to measure the SWA. For enclosed or semi-enclosed water bodies, the SWA has been determined using a geographic information system (GIS) and habitat data layers from the National Wetlands Inventory and other sources. However, for open coast species, the approximate boundaries of the SWA and larval populations are particularly difficult to determine. Estimates have been developed by considering the alongshore distance over which larvae vulnerable to entrainment may disperse to the intake. This is determined by considering the period of larval duration and the distance along the coast those larvae could have traveled during that time, which is measured by the net current displacement (that is, the distance water could have traveled during that time). The alongshore length of the SWA is then determined by multiplying the period of larval duration by the net current displacement. This length is multiplied by a constant for offshore distance (the width of the area of plankton sampling) to determine the SWA (Steinbeck et al. 2007).

3.2.2 The HPF as REA

The second part of an HPF analysis is like a REA in that it assumes that the HPF estimate also gives the amount of replacement habitat needed to produce organisms at a level sufficient to offset the entrainment loss. For this to be a valid approximation, a number of important conditions must be met, as discussed in the following section.

3.3 Evaluation of HPF Assumptions

If the PM is used as a straight multiplier to determine the amount of replacement habitat (that is, PM × SWA = HPF = area of replacement habitat), the SWA must have the following characteristics in order to provide a valid estimate of the area of replacement habitat needed to increase larval production to the level needed to offset entrainment losses:

- The replacement habitat and the SWA must have very similar species (and species mix), age distributions, and immigration/emigration relationships.
- The replacement habitat must have the same productive capacity as the SWA (that is, the rate of larval production in the replacement habitat, on an areal basis, must be equivalent to the rate of larval production in the SWA).
- The replacement habitat must be capable of producing an *increase* in larval production above the baseline production that would be achieved in that habitat absent the restoration actions. (Note that preservation alone will only yield an increase in production if losses of those habitats can be reasonably expected without preservation.)
- The replacement habitat probably must be in a different location from the affected SWA to avoid offsetting any increase by exposing the larvae to entrainment.

The following sections discuss a number of issues related to these assumptions.

3.3.1 Assumption of Habitat Limitation

The HPF method implicitly assumes that entrained species are limited by the production of larvae and that larval production is limited by habitat. However, there are numerous factors that can limit fish populations, and the assumption that production is habitat-limited may not

hold for all species or life stages. For example, local populations of fishery species may be limited by fishing mortality on adults, or larvae may be limited by food availability. If such factors are limiting populations of entrained species, then restoration of larval habitat may do little to increase recruitment and offset entrainment losses, even though restoration may be beneficial to the environment in general.

3.3.2 Standing Stock Compared to Rate of Fish Production

The HPF approach implicitly assumes that there will be an increase in the numbers or biomass of entrained fish in a replacement habitat based on knowledge of larval standing stock (that is, the PM and HPF are referenced to larval density in the SWA). However, standing stock is a measure of fish per unit area at a single point of time, not a measure of the rate of change in fish production (fish produced per unit area per unit time). For restoration scaling, the appropriate unit of comparison includes both area and time (NOAA 1997).

Even if habitat limitation is found to be a factor for species of concern, habitat restoration will only augment larval production if baseline conditions in the replacement habitat are suppressing current production. The goal of restoration is to *increase* baseline production in a replacement habitat at a scale that will *augment* production sufficiently to offset losses. Therefore, restoration scaling requires measures of *recruitment* (the addition of new recruits to the population per unit time) or *productivity* (the rate of biomass production per unit time). The density of organisms in the water column is a measure of standing stock, which may not correlate with recruitment or productivity.

Standing stock refers to the abundance or biomass of organisms within a unit area at a single instant in time, and is therefore not a measure of population change. In fact, species with the same standing stock may have very different rates of production. For example, a population of large, slow-growing individuals with low productivity could have the same standing stock as a population of small, fast-growing individuals with high productivity.

Standing stock can be used to estimate productivity only if: (1) those individuals observed at the time of abundance sampling are all the individuals of the age sampled that will be produced that year, (2) there is no turnover, and (3) there is no immigration or emigration. Abundance may be less than production if there is immigration, multiple spawning bouts not covered by the sampling regime, or sampling inefficiency (including gear inefficiency or failure to adequately sample a patchy habitat). Abundance may be greater than production if there is emigration.

3.3.3 Definition of the Source Water Area (SWA)

For HPF results to be valid, the SWA must meet the following conditions:

- The SWA must comprise relatively uniform habitat, with organisms evenly distributed in the SWA, or larval sampling of the SWA must accommodate patchy distributions

- The larval population in the SWA must be a closed or semi-enclosed population or the areal extent of the SWA and the distance and timing of larval dispersal into the area must be known.

There are realistic circumstances that can violate these assumptions. For example, the areal extent of the SWA may be too difficult to determine reliably if the hydrodynamics of the SWA and the zone of influence of the intake are too complex to determine larval dispersal, such as when intakes are located on oceans or waters connected to an ocean that are subject to strong currents or tidal influences (Steinbeck et al. 2007).

A highly variable PM over time could indicate that larvae in the SWA are fluctuating differently than the larvae being entrained, which could indicate inadequate understanding of hydrodynamics or larval dispersal distances.

3.3.4 Interpretation of Proportional Mortality (PM)

The PM is difficult to interpret without knowledge of absolute losses and the extent of the SWA. Proportional mortality estimates have been found to be very small for wide-ranging species with a large SWA, such as northern anchovy and other small pelagic species, or as high as 50 percent for larvae spawned near power plants with a smaller SWA (Steinbeck et al. 2007). It is not necessarily true however, that a small PM represents a large impact or a large PM represents a large impact. A species with a small PM in a small area will obviously experience a larger impact than a wide-ranging species with the same PM. Likewise, a species with a large PM and a large population area relative to the SWA may experience a relatively minor impact compared to a species with the same PM in a small, confined area that represents most of the SWA and the area containing the population (Steinbeck et al. 2007).

Where larvae are distributed over long distances, such as along open coasts where the ratio of cooling water volume to source water volume is low, proportional losses may appear small even though absolute losses are high (Steinbeck et al. 2007). On the one hand, this could be interpreted as meaning that losses are insignificant because a low PM means that only a small fraction of the total larval population is lost. On the other hand, if the permitting focus is to minimize entrainment, then absolute loss is the endpoint of interest, and the fraction of larvae lost is not as relevant.

More important, although the PM indicates the fraction of the larvae entrained, this loss is to the current generation only. The PM does not provide an assessment of the reproductive potential of the adult spawning stock, and therefore it does not inform the question of population sustainability or ecological significance.

3.3.5 Habitat Equivalency

The HPF approach does not examine equivalence directly, but implicitly assumes that all acres of habitat producing entrained organisms and being restored are equal with a simple one-to-one relationship, on an areal basis, between losses and gains. However, the method establishes a balancing equation based on different types of habitat, defining losses in units of wetted area and gains in units of nearshore habitats that produce larvae.

Moreover, it is almost never the case that the ecological quality of a restored habitat is comparable to that of the original habitat (Strange et al. 2002). In fact, a recent review of fish habitat restoration projects in Canada found that even use of a mitigation ratio of 2:1 was not sufficient to ensure "no net loss" for all projects (Quigley and Harper 2006).

Another complicating factor is that the habitat targeted for restoration, regardless of quality, may currently support some "baseline" amount of fish production. In such cases, the restoration gains must be assessed as the incremental change in quality, not simply the quality after restoration (NOAA 2006).

The implications of habitat differences for the scale of restoration can be illustrated using a generalization of the basic HPF method that accounts for quality differences, expressed as:

$$Ar = (PM \times SWA) \times qi / (qr - qb) \qquad \text{(Equation 2)}$$

where:

Ar is the area of restored habitat

PM is the PM in the SWA

SWA is the area containing larvae at risk of entrainment

qi is the relative habitat quality within the SWA

qr is the relative habitat quality of the Ar after restoration

qb is the relative habitat quality of the Ar before restoration.

This formulation allows for the unlikely possibility that restored habitat is superior to the habitat of the SWA ($qr > qi$). More likely are situations where restored habitat is inferior to the habitat of the SWA ($qr < qi$). In such cases, the area needed for restoration will be larger [$Ar > (PM \times SWA)$] than that calculated by the HPF [$Ar = (PM \times SWA)$]. Figure 1 is a graphical representation of some different habitat quality scenarios.

In one recent case (Huntington Beach), resource agencies have considered addressing potential inequalities among habitats, using so-called "mitigation ratios" or "conversion factors." Mitigation ratios were originally devised to ensure that wetland mitigation activities achieved the goal of "no net loss" of wetland area and services. The purpose of mitigation ratios is to help achieve an appropriate scale of restoration when wetland habitats differ in type or quality or when there are significant uncertainties about habitat productivity. However, if such ratios are selected without a formal analysis using available ecological information, uncertainties about whether proposed restoration will offset entrainment losses will not be resolved. In such cases, the results of restoration monitoring are necessary to determine appropriate ratios and potential adjustments in the amount of restoration.

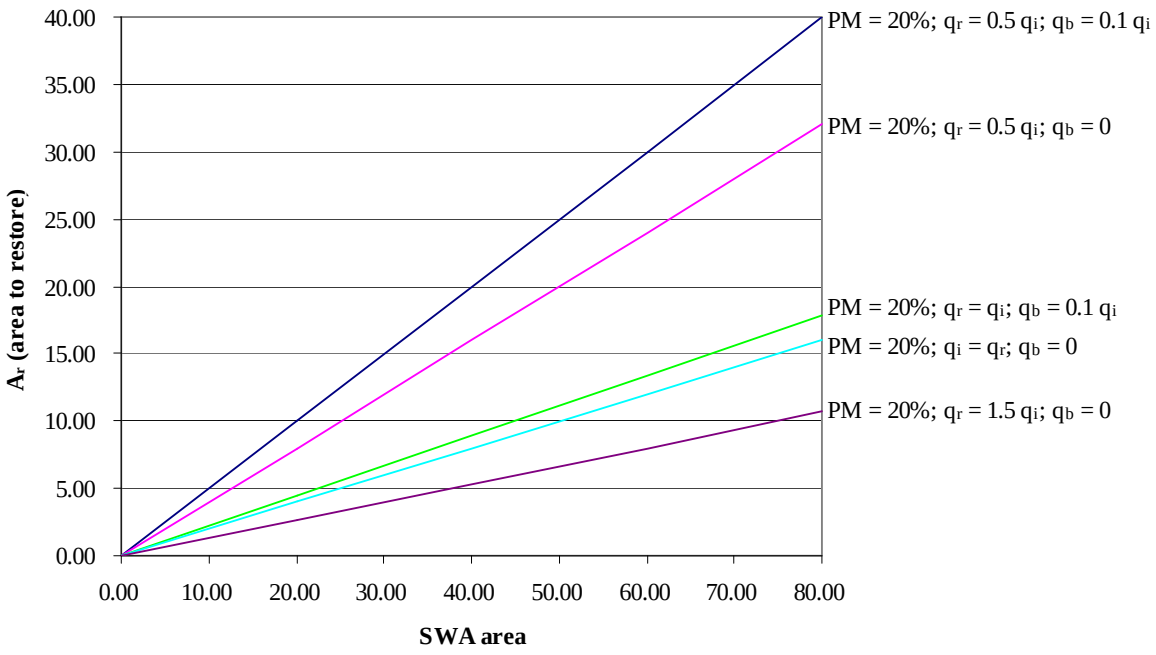

Figure 1: The relationship between the size of SWA and the size of the replacement habitat (A_r) under different hypothetical scenarios in which values are varied for the habitat quality of the replacement habitat before (q_b) and after restoration (q_r) relative to that of the SWA (q_i).

3.3.6 Scaling Based on Averages

The HPF scales restoration based on the *average* SWA and the *average* PM for the species of concern. An argument presented in favor of averaging is that each taxon can be considered an independent sample from the collection of all taxa that are entrained, and therefore the mean of several of these samples can be used to represent the loss rate for all entrained taxa (Steinbeck et al. 2007). In addition, the assumption is made that the estimate of impact becomes more reliable with increasing sample size (that is, the number of species evaluated) (Davis et al. 2006b).

However, the average PM is difficult to interpret when the size of the SWA differs by species. The situation is analogous to the problem of averaging several ratios when the denominators are different. This kind of averaging strongly influences HPF estimates of the area of replacement habitat needed to offset losses.

This problem is illustrated in Table 1 for a simple hypothetical example for two species, where the respective populations do not increase in the same proportion as the size of the SWA, such as when a species depends on a specific habitat that is not uniformly distributed in a region.

Table 1: Hypothetical example illustrating variation in average PMs resulting from differences in the estimated size of the source areas used in the averaging

Fish species	Estimated larvae in a 10 km² area	Estimated larvae in a 50 km² area	Larvae lost to entrainment in sampling period	PM assuming a 10 km² source area	PM assuming a 50 km² source area
A	1,000	2,000	500	50%	25%
B	2,000	10,000	1,000	50%	10%

PM averaging method	Average PM
Average PM assuming a 10 km² source area for both Species A and Species B	50.0%
Average PM assuming a 50 km² source area for both Species A and Species B	17.5%
Average PM assuming a 50 km² source area for Species A and a 10 km² area for Species B	37.5%
Average PM assuming a 10 km² source area for Species A and a 50 km² area for Species B	30.0%

Specifically, assume that Species A and Species B are both entrained by the intakes of power plant Y, and they have different larval population sizes (that vary differently between species as SWA size increases) and different entrainment rates. If the PMs for the two species are calculated on the basis of an estimated source area of 10 km², then the PM for both species is 50 percent (see Table 2). If these PMs are averaged, then the average PM is also 50 percent. If instead, the SWA for both species is estimated as 50 km², then the calculated PM for Species A is 25 percent, while the calculated PM for Species B is 10 percent (see Table 1). In this case, the average of the PMs is only 17.25 percent.

Table 2:. Alternative HPF estimates of the scale of restoration using the different averaging scenarios provided in Table 1

PM calculation	Average PM	Average source area	HPF (average PM × average source area)
Average PM assuming a 10 km² source area	50.0%	10 km²	5.00 km²
Average PM assuming a 50 km² source area	17.5%	50 km²	8.75 km²
Average PM assuming a 50 km² source area for Species A and a 10 km² source area for Species B	37.5%	30 km² (average of the 10 km² and 50 km² source areas)	11.25 km²

PM calculation	Average PM	Average source area	HPF (average PM × average source area)
Average PM assuming a 10 km^2 source area for Species A and a 50 km^2 source area for Species B	30.0%	30 km^2 (average of the 10 km^2 and 50 km^2 source areas)	9.00 km^2

Now consider what happens to the average PM when the estimated SWAs for the two species are different. If the PM of Species A is 25 percent based on an estimated SWA of 50 square kilometers (km^2), and the PM of Species B is 50 percent based on an estimated SWA of 10 km^2, then the average PM is 37.5 percent. But if the PM of Species A is 50 percent based on a 10 km^2 SWA, while the PM of Species B is 10 percent based on a 50 km^2 SWA, then the average is only 30 percent.

Thus, the PM calculation is very sensitive to the size of the SWA, and therefore to the assumptions that are used to estimate the SWA. In turn, the effects of the size of the SWA, on the PM and average PM, influences the results of the restoration scaling. Using the information in Table 1, Table 2 shows that the scale of restoration to offset the entrainment of Species A and Species B will vary from 5 to 11 km^2, depending on estimates of the average PM and the average SWA.

Another consequence of averaging is that the amount of restoration may be insufficient to offset the losses of any species requiring more habitat than the average. This is one reason that the scale of restoration is often based on the species requiring the maximum amount of restoration (for example, Strange et al. 2004a, 2004b; Allen et al. 2005b).

In most cases it will be important to account for all species losses individually, particularly if there is significant variation in their habitat requirements, life history, or other characteristics such as rarity (for example, threatened and endangered species). In fact, it is often argued that all species should be included in loss estimates, particularly when the assessment is part of a cost-benefit analysis (for example, Suter 2005).

3.3.7 Discounting

The HPF method does not incorporate discounting. This is not necessary when ongoing restoration actions match ongoing entrainment losses. However, if restoration is put in place to offset past entrainment, or if it will be some time before the restoration begins to produce fish at the level needed to offset losses, then discounting is needed to express losses and gains in terms of a common year. This makes it possible to compare the timing and duration of losses with the predicted timing and trajectory of restoration gains (Julius 1999; NOAA 1999).

Discounting converts losses and gains into "present value equivalents." This is done to account for the fact that gains in fish production in the future as a result of restoration are less valuable

to the public than fish available now, much in the way a dollar now is worth more than a dollar later.

The discount factor is:

$$(1 + d)^y \qquad \text{(Equation 3)}$$

where:

d is the discount rate

y represents the number of years before or after entrainment, calculated as y = year of entrainment – year of interest.

For example, to account for the delay between the time of entrainment loss and the time that restoration achieves the targeted level of fish production, discounting is used to express the total value of restoration gains over all years (TV) in terms of the year of the loss:

$$TV = \sum V_y \, [1 / (1 + d)]^y \qquad \text{(Equation 4)}$$

where:

V_y is the value y years after the loss.

The National Oceanic and Atmospheric Administration (NOAA) and other resource agencies typically use a discount rate of 3 percent for discounting public resources and values (Julius 1999; NOAA 1999).

3.4 Evaluation of HPF Analyses

The HPF method has been used to estimate the scale of restoration needed to offset entrainment losses at Moss Landing, Morro Bay, Diablo Canyon, and Huntington Beach. Table 3 summarizes the results of HPF analyses for the four power plants, followed by an evaluation of the analyses in terms of the issues outlined in Section 3.3.

3.4.1 Moss Landing Power Plant

The HPF method was first used for the Moss Landing Power Plant (MLPP) modernization project. The MLPP is located near Moss Landing Harbor, about 12 miles northwest of the Town of Salinas on the Central Coast of California, adjacent to Monterey Bay. In 1999, the facility operator proposed to modernize the facility. Units 1 through 5 of the facility's seven generating units were retired in 1995. The proposed modernization added two, 530 MW, natural gas-fired, combined cycle units that utilized the intake system of the retired units and the discharge structure for Units 6 and 7. In addition, Units 6 and 7 were upgraded by 73 MW. Combined, the new units and Units 6 and 7 use about 850 million gallons per day (MGD) of seawater for cooling (Duke Energy 2000).

The organisms entrained were assumed to use Elkhorn Slough as their primary habitat. Elkhorn Slough is a protected area north of the MLPP with tidal marshes, mudflats, and shallow open water habitat. Eight "target taxa" (that is, the most abundant species/taxa in entrainment samples) included unidentified gobies, bay goby, blackeye goby, longjaw mudsucker, blennies, Pacific herring, white croaker, and Pacific staghorn sculpin. These species made up 95 percent of all entrained larvae collected in entrainment sampling, and were considered "proxy species" for all entrained species (Tenera 2000b).

Table 3: Summary of results of HPF analyses for four coastal power plants in California

Power plant	Annual entrainment of fish species included in HPF estimate (rounded)	PM_{AVG} for fish species included in HPF analysis (%)	SWA used for HPF analysis	**Amount of restoration estimated by HPF**	Estimated cost of proposed restoration
Moss Landing Power Plant (MLPP)[a]	All target species: Unidentified gobies – 2.7×10^8 Bay goby – 1.5×10^8 Blackeye goby – 1.7×10^7 Longjaw mudsucker – 8.0×10^6 Blennies – 1.7×10^7 Pacific herring – 4.4×10^6 White croaker – 8.6×10^6 Pacific staghorn sculpin – 8.6×10^6	13	3,000 acres	390 wetland acres	$7,000,000
Morro Bay Power Plant (MBPP) [b]	Bay species only: Unidentified gobies – 3.9×10^8 Shadow goby – 1.3×10^7 Combtooth blennies – 1.0×10^7 Jacksmelt – 6.3×10^6 Pacific herring – 3.0×10^6	33	2,300 acres	759 acres	$28,000,000
Diablo Canyon Power Plant (DCPP)[c]	Rocky reef fishes only: Smoothhead sculpin – 8.6×10^7 Monkeyface prickleback – 7.2×10^7 Clinid kelpfishes – 2.4×10^8 Blackeye goby – 1.2×10^8 Cabezon – 4.4×10^7 Snubnose sculpin – 9.7×10^7 Painted greenling – 1.7×10^7 KGB rockfishes – 2.5×10^8	10.76	Not reported in HPF document reviewed	200–1,000 acres artificial reef	$10,000,000–$50,000,000

	Blue rockfish – 5.9×10^7

Table 3. Summary of results of HPF analyses for four coastal power plants in California (cont.)

Power plant	Annual entrainment of fish species included in HPF estimate	PM_{AVG} for fish species included in HPF analysis (%)	SWA used for HPF analysis	**Amount of restoration estimated by HPF**	Estimated cost of proposed restoration
Huntington Beach Generating Station (HBGS)[d]	Soft bottom species only: Spotfin croaker – 7.0×10^6 Queenfish – 1.8×10^6 White croaker – 1.8×10^6 Black croaker – 7.1×10^5 Blennies – 7.2×10^5 Diamond turbot – 5.4×10^5 California halibut – 5.0×10^5 Rock crab – 6.4×10^5	0.56	Three estimates of the SWA reported: 0.11 km^2, 4.47 km^2, and an average of 1.50 km^2. Area used for Energy Commission HPF estimate not given in document reviewed.	208 wetland acres (all units), 104 acres (Units 3 and 4)	$7,956,000 (for 104 acres)

a. From Table 3 and accompanying text by Dr. Pete Raimondi, University of California at Santa Cruz, in Strange et al. (2004a) based on data in Tenera (2000b). PM and HPF estimates were based on the estimated average period that larvae are at risk of entrainment.
b. From CCRWQCB (2004). PM and HPF estimates were based on estimated maximum period larvae are at risk. Coastal taxa (staghorn sculpin, northern lampfish, rockfishes, white croaker, cabezon) had a PM_{AVG} of 3% and were not included in the HPF analysis. Estimated SWA was the Morro Bay Estuary. Restoration cost was based on an estimated cost of $37,000 per acre developed by staff of the Central Coast Regional Water Quality Control Board and the Morro Bay National Estuary Program, assuming restoration costs of $26,000 per acre and an average purchase cost for ideal floodplain habitat of $11,000 acre.
c. From Raimondi et al. (2005). Restoration cost is based on an estimated cost of $50,000 per acre based on costing information for the San Clemente Artificial Reef (SCAR). Entrainment estimates are average of sampling periods 1 (1996–1997) and 2 (1997–1998) from Table 1 of Raimondi et al. (2005). Sampling period 3 overlapped period 2, and therefore was not included in the entrainment estimates.
d. HPF estimates are from Biology Table 2 of Davis et al. (2006b), included with California Energy Commission's Order Requiring Post-Licensing Studies, posted online 10/4/2006 at http://energy.ca.gov/sitingcases/huntingtonbeach/compliance/index.html. Estimates in table were based on permitted flow of 507 MGD. Restoration cost was based on an estimate of $74,660 per acre for initial restoration costs and $784 per acre for

operation and maintenance provided by restoration experts working on the Huntington Beach Wetlands. Final Energy Commission decision was based on actual operational flow of 235.5 MGD for Units 3 and 4, and required 66.8 acres and $5,511,000. Analysts did not include two target taxa—gobies and northern anchovies—in the HPF analysis, because they argued that gobies do not occur near Huntington Beach Generating Station (HBGS) as adults, and northern anchovies occur over a much larger area than the nearshore SWA (Davis et al. 2006b).

Restoration scaling using the HPF method was based on the PM_{AVG} for the eight target species, which was 13 percent based on the average period that larvae were considered at risk of entrainment, and 28 percent based on the maximum potential period at risk. From GIS mapping, analysts concluded that there were 3,000 acres of relatively enclosed aquatic habitat in Elkhorn Slough that are subject to inundation and therefore could support the organisms subject to entrainment. This area was considered the SWA. Using this SWA estimate and the two PM estimates, the HPF analysis estimated that the amount of restoration needed to offset entrainment at MLPP was between 390 acres (13 percent × 3,000 acres) and 840 acres (28 percent × 3,000 acres). The final negotiated settlement was for restoration of 390 acres at an estimated cost of $7,000,000 (Energy Resources and Conservation and Development Commission 2000).

As summarized in Table 4, the HPF analysis for the MLPP meets some critical assumptions for HPF validity. Specifically, the SWA of entrained larvae could be defined relatively unambiguously, and there is evidence that the SWA is a source of larval production for at least some entrained species. Longjaw mudsucker and Pacific herring, for example, reportedly spawn in Elkhorn Slough (Duke Energy 2000). There are also studies indicating that other target species (for example, gobies) are marsh residents (for example, Yoklavich et al. 1991).

However, because the replacement habitat is within the affected area, it may not increase larval production, particularly to the level needed to offset losses (that is, as more larvae are produced in Elkhorn Slough, more larvae may be entrained).

Two major shortcomings of the Moss Landing Power Plant HPF are common to all HPF analyses. First, the HPF assumes a 1:1 relationship between annual entrainment losses each year and the annual gains produced in the replacement habitat. In addition, the HPF assumes that the density of larvae in the water column, estimated from ETM modeling, is equivalent to larval productivity and can be taken as an estimate of the *increase* in larval production needed to offset entrainment. As discussed previously, for this assumption to be valid it must be shown that (1) those individuals observed at the time of abundance sampling are all the individuals of the age sampled that will be produced that year, (2) there is no turnover, and (3) there is no immigration or emigration.

Table 4: Summary of analysis of HPF assumptions for the MLPP, MBPP, DCPP, and HBGS

Power plant	SWA used to estimate HPF	Replacement habitat	Larval production is habitat-limited	Replacement habitat includes source of larval production	Aerial extent of SWA can be reliably determined	Habitat of SWA is uniform and larvae are evenly distributed
Moss Landing	Elkhorn Slough, which contains open water, marsh mudflats, tidal creeks	Same	No evidence provided, but likely for resident species and assumption is consistent with efforts to restore Elkhorn Slough	Evidence for longjaw mudsucker, Pacific herring	Yes	No. SWA contains diverse habitats, and larval densities are likely to be greater in marsh, mudflats, and tidal creeks than in open water.
Morro Bay	Open water of bay	No replacement habitat proposed; HPF estimates used to develop cost estimates for sediment reduction program	No evidence provided, but likely for bay species because of habitat degradation in the estuary	No evidence provided, but nearshore habitats of bay are likely areas of larval production for bay species	Yes, for the bay SWA	No. SWA contains diverse habitats, and larval densities are likely to be greater in marsh, mudflats, and tidal creeks than in open water.
Diablo Canyon	Open coast	Rocky reef	No evidence provided, but unlikely for open coast species	Unknown and difficult to determine	No	No information provided, but likely in coastal waters
Huntington Beach	Soft-bottom habitat	Wetlands	No evidence provided, but unlikely for open coast species	Unknown and difficult to determine	No	No information provided, but likely in coastal waters

Note: See text for details.

3.4.2 Morro Bay Power Plant

The Morro Bay Power Plant (MBPP) is located on the northeastern shore of Morro Bay near the city of Morro Bay in central California. The intake of the MBPP entrains both bay and nearshore coastal taxa, and therefore it was necessary to divide the SWA into two sub-areas, bay water and nearshore coastal water, for purposes of ETM modeling. Calculation of the SWA was also complicated because the intake is subject to daily tidal flows. The large tidal exchange in the bay results in rapid turnover of bay waters. The volume of the Morro Bay component of the SWA was estimated as the sum of the bay's nontidal volume and the twice daily tidal exchange of the bay's average tidal prism, adjusted for tidal exchange. The area outside of Morro Bay in Estero Bay was treated as a static volume equal to the volume of Morro Bay uncorrected for tidal exchange. The size of the SWA beyond these sampled areas was estimated using current data. (Steinbeck et al. 2007).

An HPF analysis for the MBPP was based only on bay species and the bay SWA. As shown in Table 4, the PM was estimated as 33 percent, and the SWA was estimated as 2,300 acres, resulting in an estimated replacement habitat of 759 acres (33 percent × 2,300; CCRWQCB 2004). This analysis assumes, like other HPF analyses, that standing stock can be used as a proxy for rates of larval production in the replacement habitat, and also fails to consider power plant losses and restoration gains over time. The facility presented a proposal for a Habitat Enhancement Program (HEP) that had similar flaws, including the failure to show the nexus between the loss of larvae from entrainment and the gain in larval production as a result of restoration (Duke Energy 2002).[4] In addition, the HPF analysis incorrectly used the cost to purchase and/or restore the estimated amount of replacement habitat as a proxy for the value of entrainment losses (see Section 3.8 for discussion of appropriate use of habitat replacement costs). Based on these costs, the Regional Board concluded that the total value of the entrainment losses is $8.5 million (based on the facility's assumption of a 10 percent larval loss) or $28 million (based on the staff's assumption of a 33 percent larval loss; CCRWQCB 2004).

3.4.3 Diablo Canyon Power Plant

The Diablo Canyon Power Plant (DCPP) is a nuclear-fueled generating facility located on the open coast in central California, between the cities of Morro Bay and Avila Beach. Local biologists determined that almost all of the fish species lost to entrainment at DCPP are associated with shallow rocky reefs. Therefore, the HPF analysis for DCPP focused on estimating the amount of rocky reef habitat that would be needed to offset entrainment losses of rocky reef fishes (Raimondi et al. 2005).

---

[4]. The HEP used what it described as an HEA analysis, but in many important respects it was incorrectly designed and implemented, invalidating the HEA results.

The amount of rocky reef restoration needed to offset entrainment losses was estimated by multiplying the PM_{AVG} for the rocky reef fishes entrained (10.76 percent) by the estimated area of rocky reef within the SWA_{AVG} of the nine species. Two alongshore areas were selected as potential locations of the SWA, one centered at the DCPP and the other with a southern limit near the DCPP. Within each location, the SWA was assumed to be an area 74 kilometers (km) alongshore (the average alongshore distance traveled by the vulnerable larvae of the nine target species) and 3 km offshore (the offshore distance of the fish sampling grid). Two PMs were developed for each species based on each of these SWAs, with each SWA a function of the species-specific duration of the dispersing stage of the larvae and the oceanographic currents that transport the larvae along the coast (Raimondi et al. 2005).

The area of rocky reef within each of these areas was determined by overlaying each of the potential average SWAs with a map of kelp coverage in that area, based on the assumption that most rocky reef along California's Central Coast that occurs between 5 and 30 meters in depth is likely to be covered by kelp. Because the area of offshore rocky reefs not covered by kelp is more difficult to estimate, the analysts applied a multiplier of 2 to this estimate to account for potential offshore reef area (Raimondi et al. 2005).

Entrainment and HPF estimates are presented in Table 4. Applying the PM_{AVG} (10.76 percent) to the two estimates of rocky reef area within each SWA_{AVG} resulted in an estimate of the amount of artificial reef needed to compensate for DCPP entrainment of rocky reef fishes that ranged from 200 acres to 1,000 acres (Raimondi et al. 2005).

The HPF estimates are particularly difficult to interpret in this case. The effort to define the SWA for this ocean facility involved considerable effort and ingenuity, but there was still significant uncertainty in the resulting estimates. Improving the SWA estimates based on this approach would require even more extensive and costly analysis of ocean currents and larval dispersal, and it is unclear whether the uncertainty could be reduced sufficiently. The period of larval duration is particularly difficult to determine for pelagic species.

More importantly, whether rocky reefs are a source of production or simply attract larvae remains a subject of debate within the scientific community (Bohnsack 1989; Bohnsack et al. 1994; Grossman et al. 1997). However, even if the reef restoration led to an increase in production, it would be necessary to manage fishing around the reef to ensure that the expected production was realized (Powers et al. 2003).

3.4.4 Huntington Beach Generating Station

The Huntington Beach Generating Station (HBGS) is located in Huntington Beach, in Orange County, California. Marine habitat near the facility is primarily sandy substrate. The Huntington Beach Wetlands, dominated by pickleweed (*Salicornia virginica*), occurs to the southeast and northwest of the facility. The intake of the HBGS is offshore in subtidal, sand-bottom habitat, and therefore most of species entrained are soft-bottom species (for example, croakers; MBC Applied Environmental Sciences and Tenera Environmental 2005).

In May 2001, the HBGS received approval from the Energy Commission to restore and restart Units 3 and 4 for operation until September 2011, after the units had been retired in 1995. In 2003, Units 3 and 4 became operational, and since that time intake flows for Units 3 and 4 have averaged 235.5 MGD. Total flow for all units is 507 MGD (MBC Applied Environmental Sciences and Tenera Environmental 2005).

Entrainment at the HBGS was estimated from plankton samples taken just offshore of the intake and based on the total intake flow of 507 MGD. Sampling identified a total of 57 taxa, but subsequent analyses focused on the most abundant taxa (target taxa), including three estuarine fish species (arrow goby, cheekspot goby, and shadow goby; collectively known as *CIQ gobies),* seven coastal fish species (white croaker, black croaker, spotfin croaker, queenfish, blennies, diamond turbot, and California halibut), and rock crab megalops. Source water populations of larvae were estimated from samples collected at the station and six other stations extending 4 km upcoast, downcoast, and offshore of the intake structure (Davis et al. 2006b).

Because the refurbishing of Units 3 and 4 is considered a new source of entrainment, the impact analysis was for entrainment at these two units only. Intake flow and entrainment for Units 3 and 4 is about half of total at HBGS (Davis et al. 2006b).

Two estimates of the SWA were developed using two different alongshore lengths: one based only on alongshore current movement (12.8 km) and the other based on both alongshore current and an extrapolation of larval densities offshore to a distance bounded by either the extrapolated densities or the onshore current (84.9 km). The width of the SWA was based on the area of plankton sampling (5 km). On this basis, the two estimates of the SWA were 0.11 km^2 and 4.47 km^2, or an average of 1.50 km^2 (MBC Applied Environmental Sciences and Tenera Environmental 2005).

Table 4 presents entrainment and HPF estimates for target species found in soft-bottom habitat. Because there is no practical method to create soft-bottom habitat, the restoration proposal focused on out-of-kind restoration, specifically wetland restoration.[5] The HPF estimate, based on the PM_{AVG} and SWA_{AVG} for the target species, was 104 acres based on entrainment at Units 3 and 4 (Davis et al. 2006b). Two target taxa, gobies and northern anchovies, were not included in this HPF analysis, because gobies do not occur near HBGS as adults, and northern anchovies occur over a much larger area than the nearshore SWA (Davis et al. 2006b).

An alternative HPF estimate by facility consultants used goby for scaling because most of the entrainment is of goby, which are produced in wetlands, specifically in mudflat habitat. The HPF estimate for the CIQ goby complex was 15.35 acres (Davis et al. 2006b).

The total cost to restore 104 wetland acres was based on estimates of $74,660 per acre for initial restoration costs and $784 per acre for operation and maintenance, for a total of $75,444. Cost estimates were developed by restoration experts working on the Huntington Beach Wetlands

[5]. In southern California, there is a history of restoring coastal wetlands or artificial reefs as mitigation for losses of soft-bottom species (Davis et al. 2006b).

(Davis et al. 2006b). Assuming a maintenance period of 10 years (the term of the HBGS license), the cost to restore the 104 acres was estimated as $7,956,000 (Davis et al. 2006b).

Like the HPF for the DCPP, a significant limitation of the HPF analysis for the HBGS is the difficulty in defining the SWA. As the HBGS entrainment study noted, the larval dispersal distance used to define the SWA for larvae entrained by coastal intakes has a significant influence on ETM estimates of entrainment and the PM (MBC Applied Environmental Sciences and Tenera Environmental 2005).

3.4.5 Summary of Omissions, Biases, and Uncertainties in HPF Analyses

Table 5 provides a summary of how particular HPF assumptions may affect estimates of the appropriate scale of needed restoration. The potential implications are uncertain for some assumptions. For example, the common inability to reliably convert entrainment losses into a proportion of the SWA, could either under- or over-estimate actual rates of larval production. On the other hand, the directions of some other biases are clear. For instance, the lack of discounting will result in a potentially significant underestimate of the scale of future restoration required to offset past and continuing losses.

Taken together, the biases of the HPF have the potential to significantly underestimate the scale of restoration required to offset entrainment losses.

Table 5: Summary of omissions, biases, and uncertainties in HPF scaling

Issue	Comment	Effect on estimated scale of restoration
HPF assumes that ETM sampling of open waters of SWA samples larval habitats	Nearshore habitats such as marshes, tidal creeks, mudflats, and submerged aquatic vegetation (SAV) are not sampled.	Potentially large in either direction
HPF must assign an SWA, even when hydrodynamics, habitat diversity, and entrainment life histories are too complicated to be modeled reliably	Few intakes are located where simplifying assumptions will be valid; a highly variable PM over time may indicate issues.	Potentially large in either direction
HPF assumes the density of organisms in SWA at the time of sampling is equal to the rate of larval production	Measures of standing stock can only be used as a proxy for rates of production under very limited circumstances (that is, when all the organisms recruited to the population that year are sampled and there is no immigration or emigration between the time of larval production and the time of sampling).	Underestimate
HPF averages PM and SWA for multiple species	Average PM and average SWA are not meaningful. Restoration requirements depend on each species' habitat requirements. Scaling should be based on the species requiring the maximum.	Underestimate
HPF evaluates habitat losses and gains without accounting for time, including discounting	Losses and gains occur over time, not in a single instant.	Underestimate
HPF assumes SWA habitats produce larvae	Local habitats may not be the source of local larvae.	Unknown
HPF assumes SWA and replacement habitat are equivalent in quality	Restored habitat rarely functions as well as existing habitat. However, restoration sites may occasionally be available that are better than habitats that happen to be in the SWA.	Usually underestimate
HPF assumes larval habitat is limiting for local fish populations	The factors that limit affected populations must be demonstrated.	Underestimate if assumption is not met

3.5 HPF Alternatives

3.5.1 Alternative Scaling Approach

A straightforward alternative to the HPF approach would compare directly the measure of larval entrainment with gains in larvae from habitat restoration. This involves quantifying the amount of habitat needed to produce organisms equivalent to those lost to entrainment (that is, the same species and life stages). In this sense, it is a hybrid of the REA and HEA scaling approaches often used in NRDA cases (NOAA 1997). In contrast to the HPF approach, such an analysis would base estimates of the amount of habitat on recruitment or production per unit area per unit time. Box 1 compares restoration estimates using the HPF method with an alternative analysis using data in the scientific literature on rates of production.

Unlike the HPF, this type of approach does not require larval sampling of the water body to determine the size of the larval population of each species and the portion of each larval

Box 1. Comparison of methods used to estimate acres of restoration needed to offset entrainment of CIQ gobies

HBGS consultants estimated the amount of replacement wetland to offset entrainment of the CIQ goby complex as 15.35 acres using the HPF method.[a] An alternative approach is to estimate the rate of goby production from the scientific literature. Allen (1982) provides data for goby production in the littoral zone in Upper Newport Bay in southern California of 0.2026 grams dry weight per square meter per year (g dw m^{-2} yr^{-1}), or 820 g dw ac^{-1} yr^{-1}. Over a ten-year license period, the present value equivalent of this annual production using a 3 percent discount[b] rate is 82,820 g dw ac^{-1}.

Using the productivity estimate from Allen (1982), the acreage to be restored is estimated by dividing the entrainment loss of gobies, expressed as present value dry weight loss of gobies over the 10-year license period (338,315,003), by the present value dry weight gain of gobies per acre over the license period (82,820 g dw ac^{-1}). This results in an estimate of 4,085 acres of restoration required to offset annual goby entrainment over the next 10 years.

The difference in cost using the two methods is also substantial. Therefore, determining the best estimate could be particularly important in settlement negotiations, even in cases where restoration is not actually implemented (e.g., for the Salem facility in Delaware Bay). Based on the cost used for HPF estimates of $75,444 per acre,[b] and using the alternative estimate of the scale of restoration for CIQ gobies (4,085 acres), the cost would be $308,182,883 – orders of magnitude higher than that based on the HPF estimate for goby of 15.35[b] acres by HBGS's consultant ($75,444 × 15.35 = $1,158,065) or the HPF estimate for all species of 104[b] acres by Energy Commission consultants ($75,444 × 104 = $7,846,176).

a. Cited in Davis et al. (2006b).

b. Discounting converts losses and gains to "present value equivalents" to account for time lags and to express results in terms of a common year (NOAA 1997, 1999; U.S. EPA 2000). NOAA and other resource agencies generally use a 3% discount rate (NOAA 1997, 1999).

population at risk of entrainment. Therefore, it does not require modeling of the complexities of SWA-wide hydrodynamics and SWA-wide larval dispersal, nor does it depend on the special circumstance of relatively uniform habitat in an easily defined SWA for which larval dispersal distances can be reliably estimated.

The main difficulty with approaches based on estimates of recruitment or rates of fish production is the lack of demographic data for many of California's marine fishes. However, a carefully designed monitoring program can help fill data gaps and indicate changes that may be necessary to ensure that the restoration will achieve its goals. The following section describes data needs and some of the methods available for estimating production rates even when demographic data are limited. The challenge for the analyst will be determining which methods, including the HPF, best balance trade-offs among data availability and ecological relevance.

Many of these techniques are drawn from examples in a special issue of the journal *Marine Ecology Progress Series* (Volume 264, 2003) which provides several examples of quantitative methods for scaling restoration, including demographic and growth models for single species and trophic transfer modeling to scale restoration across multiple trophic levels. The methods are also discussed at length in a report for the Energy Commission entitled *Research on Estimating the Environmental Benefits of Restoration to Mitigate or Avoid Environmental Impacts Caused by California Power Plant Cooling Water Intake Structures* (Strange et al. 2004a).

3.5.2 Developing Estimates of Fish Production

To estimate fish production for habitat scaling purposes, one could (1) rely on site-specific data (such as the larval data collected for parameter ρ of the ETM), or (2) rely on published information. Some of the data and methods most commonly used for developing production rates for scaling purposes are outlined below, followed by a table presenting examples of fish productivity estimates in the scientific literature.

Annual Rate of Fish Production

Fish productivity is a measure that integrates the recruitment, growth, and survival of the individuals in a cohort or population. It is a comprehensive measure of the ecological benefits of habitat restoration. Productivity estimates for each species allow determination of which species require the largest amount of restoration, which ensures that there will be sufficient restoration for all species.

A number of methods are available for estimating rates of fish production from field sampling. Cohort-based methods include (1) removal summation, (2) increment summation, (3) the instantaneous growth rate method, and (4) Allen's graphical method (Waters 1977; Newman and Martin 1983; Wootton 1990). The *removal summation* method is based on the concept that production by a cohort eventually dies or is otherwise removed. The method involves assessing the reduction in numbers in a cohort throughout its lifetime (Waters 1977).

The *increment summation* procedure involves taking samples of individual weights periodically throughout the life of the cohort. From one sample to the next, the growth increment is

estimated as the increase in mean individual weight. This estimate is multiplied by cohort numbers during the interval to estimate production during the period. The sum of all such estimates gives an estimate of production by the entire cohort (Waters 1977; Newman and Martin 1983; Morin et al. 1987).

The *instantaneous growth rate* method (Ricker 1975) assumes that the instantaneous rate of growth per unit weight, g, and the instantaneous mortality rate, Z, are constant over the time interval for which production is to be estimated (Chapman 1978; Wootton 1990). In this case:

$$P = gB_0 (e^{g-Z} - 1) / g - Z \qquad \text{(Equation 5)}$$

where:

B_0 is the biomass of the individuals in a cohort at the start of the interval.

On this basis, production can be calculated from one observation of biomass.

An extension of the Ricker (1975) instantaneous growth rate method is the *graphical* method of Allen (1971). This method estimates production using a curve in which mean individual weight, w, is plotted against cohort size, N, at particular times and then assessing the area beneath the curve (Chapman 1978; Wootton 1990).

A *cohort-free size-frequency* approach for estimating secondary productivity (Hynes 1961; Hynes and Coleman 1968) is conceptually similar to removal summation, but it involves summation of losses between successive size groups instead of successive times (Hamilton 1969; Waters 1977; Menzie 1980; Cicchetti 1998).

Production Foregone

Production foregone considers the biomass that would have been produced by the organisms lost had they lived their remaining lifetime (Rago 1984; Dixon 1999). Restoration scaling based on production foregone has included the lost production of affected individuals only (for example, French McCay et al. 2003) or alternatively, their lost production *plus* the production of progeny that were not produced because of the deaths of the affected individuals (for example, Sperduto et al. 2003).

Production: Biomass Ratio

A *production:biomass* (P:B) ratio is an index of the rate of production of the individuals within an area per unit of biomass (Randall and Minns 2000). A P:B ratio based on a one-year time frame is the ratio of annual production of those individuals to their mean annual biomass. Multiplication of the P:B ratio by mean biomass provides a measure of production when only biomass is known. Based on a review of fish production studies and P:B ratios for tidal marshes, Kneib (2003) recommends a P:B ratio of 2 for marsh fishes. Kneib (2003) notes, however, that ratios may be considerably higher for early life stages (for example, 7.55 for young-of-year fish reported by Allen 1982).

Use of Abundance as a Proxy for Production

If the P:B ratio is 1, then abundance estimates can be used as a proxy for annual production if (1) those individuals observed at the time of abundance sampling are all the individuals of the age sampled that will be produced that year, (2) there is no turnover, and (3) there is no immigration or emigration. Abundance may be less than production if there is immigration, multiple spawning bouts not covered by the sampling regime, or sampling inefficiency (including gear inefficiency or failure to adequately sample a patchy habitat). Abundance may be greater than production if there is emigration. These factors must be taken into account in determining if it is appropriate to assume that an estimate of standing stock is a reasonable surrogate for direct estimates of fish productivity.

Similar to the HPF, abundance estimates from fish surveys in the habitat types to be restored are sometimes used to estimate rates of production. Typically, survey data are reported as catch per unit effort (CPUE), the number or weight of fish taken by a defined unit of sampling effort (for example, number of fish caught per trawl). To estimate rates of production for the purpose of scaling restoration, it is necessary to use CPUE data for the relevant habitat and to convert the data to an equivalent estimate of abundance per unit area, defined by the area sampled. In most cases, CPUE data must also be adjusted to account for the sampling efficiency of the gear used, especially for early life stages. Sometimes CPUE data are available from peer-reviewed studies for specific habitat types (for example, SAV, tidal wetlands). Unfortunately, broad-based sampling programs (for example, those conducted by state or federal agencies) may record catch information with only a site identification number and without any habitat description. In such cases, discussions with individuals familiar with the sampling locations, and a review of supporting documentation (for example, annual program summaries) will enable definition of the habitat categories for sampled locations.

Estimates of sampling efficiency may occasionally be incorporated in sampling reports, but information is also available for some types of gear in the published literature (for example, Rozas 1992; Jordan et al. 1997; Rozas and Minello 1997; Bayley and Herendeen 2000). If there are no other sources of data, those conducting the sampling can be contacted for their professional estimate of the gear efficiency based on the conditions encountered or informal and unreported assessments (for example, use of underwater cameras to record field performance of trawls).

Trophic Transfer Modeling

There is increasing interest in estimating the production of communities rather than populations of single species. Trophic modeling of energy transfer through the local food web is one approach that has been used for the purposes of restoration scaling. Trophic transfer models are based on the connection between salt marsh primary production and the secondary production of both resident and transient fish and shellfish (Kneib 2003).

Kneib (2003) developed a simple trophic transfer model to estimate the annual production of nekton resulting from the annual production of *Spartina* marsh. The model is outlined in Figure 2.[6]

This type of approach was applied to estimate the marsh area needed to offset impingement and entrainment at the Salem facility in Delaware Bay (PSE&G 1999; Teal and Weinstein 2002). The model estimated the amount of fish produced by a given amount of marsh primary production based on published studies of marsh food webs in local areas (for example, a New Jersey study by Rountree and Able 1992). See Box 2 for details on this analysis.

Fish Production Estimates in the Scientific Literature

There are a number of published studies of fish production rates that have been used for restoration scaling, and a sample of these is provided in Table 6. In the absence of site-specific and species-specific data, literature values can provide a reasonable first-order approximation for scaling restoration. Once restoration activities begin, restoration monitoring can be designed to obtain the data needed to develop estimates for local species and site conditions, and the restoration can then be adapted as needed to ensure a more accurate match between entrainment losses and gains from restoration.

[6]. Note that it is important to use location-specific data for a trophic modeling approach. For example, estimates of primary production for *Spartina* marshes on the U.S. East Coast may differ, perhaps significantly, from those for *Salicornia* marshes on the Pacific Coast.

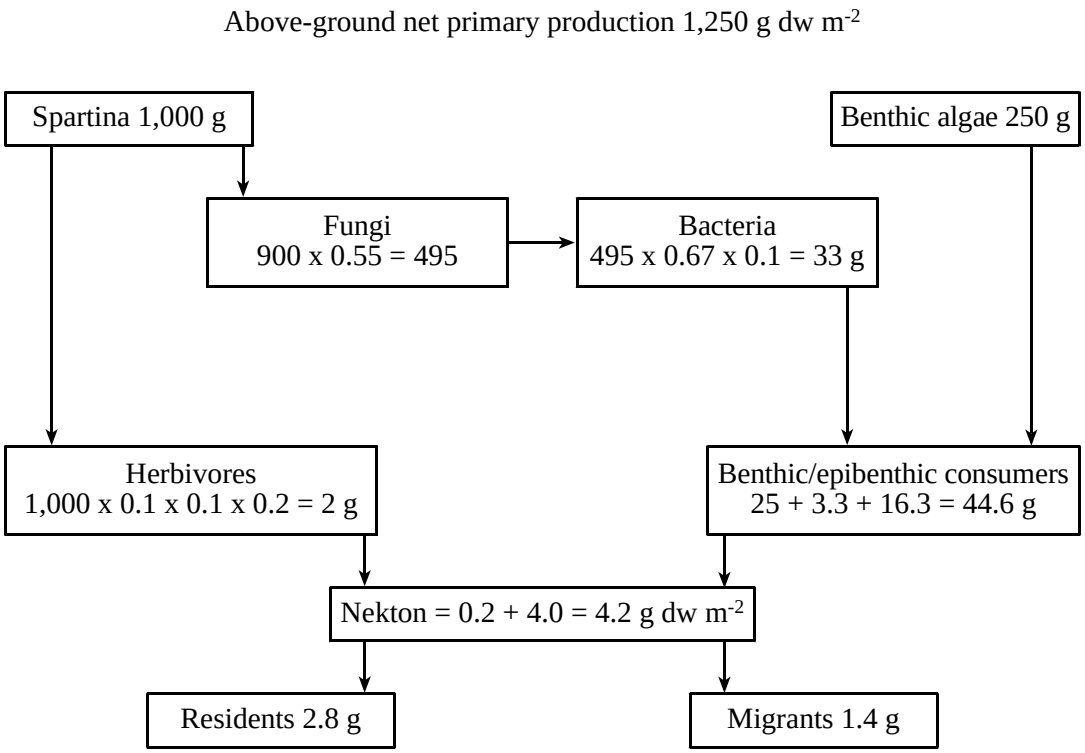

Figure 2: Production flows to nekton from net annual marsh primary production

Source: After Figure 1 in Kneib (2003).

Box 2. Example of power plant restoration scaling using a trophic modeling approach

A member of one of the agencies involved in the scaling analysis for the Salem facility in Delaware Bay summarized the trophic modeling process as follows (Freeman 2003):

Step 1: Determine total annual marsh primary production by adding estimates of primary production by marsh plants and by benthic algae:

> 72,790 lbs/ac/yr (plants) + 7,145 lbs/ac/yr (benthic algae) = 79,935 lbs primary production/ac/yr.

Step 2: Assuming that about 45 percent of this annual primary production is transported out of Delaware Bay, primary production within the bay is given as:

> 79,935/lbs/ac/yr × 0.55 = 43,964 lbs primary production/ac/yr.

Step 3: Most biomass of marsh plants passes through a detrital food web. Assuming that 40 percent of plant primary production is converted to organic detritus, then:

> 43,964 lbs/ac/yr × 0.40 = 17,586 lbs/ac/yr detritus.

Box 2. Example of power plant restoration scaling using a trophic modeling approach (cont.)

Step 5: Assume that this organic matter is converted to fish biomass as follows:
Organic matter ◎ primary consumers (arthropods) ◎ secondary consumers (age 1 fish).
Assuming a 20 percent conversion efficiency among trophic levels,[b] then the fish biomass produced is given as:

11,782 lbs/ac/yr × 0.2 × 0.2 = 471 lbs/ac/yr of fish biomass produced.

Step 6: Partition this biomass among the fish species impinged and entrained based on species-specific mortality rates for age 1 fish:

Species	Percent of total age 1 impingement and entrainment mortality (col a)	Total fish biomass (lbs/ac/yr) (col b)	Species specific production (lbs/ac/yr) (col a × col b)
Bay anchovy	36.4%	471	171
Weakfish	6.1%	471	29
Spot	9.6%	471	45
White perch	10.7%	471	50
Other fish	37.2%	471	175
Totals	100%	NA	471

Step 7: Determine the area of salt marsh (acres) needed to offset each species losses by dividing the biomass of each species lost per year (lbs/yr) by the biomass of that species produced per acre of salt marsh per year (lbs/ac/yr):

Bay anchovy: 1,280,304 lbs/yr / 171 lbs/ac/yr = 7,487 ac

Weakfish: 127,463 lbs/yr / 29 lbs/ac/yr = 4,395 ac

Spot: 252,869 lbs/yr / 45 lbs/ac/yr = 5,619 ac

White perch: 62,350 lbs/yr / 50 lbs/ac/yr = 1,247 ac

Step 8: Use the acreage for the species requiring the maximum, which in this example is 7,487 acres, as the total area to be restored.

Table 6: Estimates from the published literature of rates of secondary production in coastal habitats (in grams dry weight per square meter per year, g dw m^{-2} yr^{-1})

g dw m^{-2} yr^{-1}	Location	Source
9.4	Estuary, Upper Newport Bay, CA	Allen (1982)
8.6	Coastal Lagoon, Mexico	Warburton (1979) as cited by Allen et al. (2006)
8.4	Restored Salt Marsh, NJ	Teo and Able (2003)
1.6	Great Sippewissett Marsh, MA	Valiela et al. (1977)[a]
7.4-8.0	Marsh, Goodwin Islands, VA	Cicchetti (1998)[b]
8.1	Marsh Creek, DE	Meredith and Lotrich (1979)[c]
4.2-4.6	Marsh Creek, VA	Weinstein and Walters (1981), Weinstein (1983)
0.3-7.5	Marsh Creek, NC	Currin et al. (1984)

a. Corrected for arithmetic errors in original.
b. Estimate is for nekton (fish and shrimp) for 150 days, corrected for poorly sampled smaller size classes.
c. Wet weights converted to dry weights using a conversion factor of 0.25.

Sources: Based on Table 5-9 in Allen et al. (2006) and Table 5 in Strange et al. (2002).

Data Sources for Scaling Metrics and Data Gaps

Data needed for these scaling metrics include size-frequency data, length and weight measurements for a sample of individuals, and repeated sampling events. Empirical transport modeling studies provide much of this information, including data for multiple sampling events (for example, Tenera 2000a, 2000b, 2001; MBC Applied Environmental Sciences and Tenera Environmental 2005):

- Abundance of larvae by size class
- Lengths and weights of larvae
- Average age of larvae (estimated using otolith techniques or from average length by dividing the difference between the average and minimum lengths by a daily larval growth rate from the scientific literature).

3.5.3 Restoration Monitoring and Adaptive Management

Even using the best methods and data available for estimating annual production rates, uncertainties will remain that can be addressed with ongoing monitoring and adaptive management of restoration actions (Hilborn 1987; Julius 1999). In general, there are a lack of data to estimate potential year-to-year variability in fish abundances and production rates. There is also little information on how production rates may differ in restored habitats compared to unaltered habitats, or how rates may vary over the time horizon of a particular restoration action. Restoration monitoring focused on collecting the data needed to estimate

annual rates of production will help fill critical data gaps for measuring the success of fish restoration actions.

3.5.4 Guidelines for Restoration Scaling

Guidelines for restoration scaling include the following:

- Base scaling on fish productivity, not on standing stock.
- If such information is not available in the scientific literature or existing larval sampling data, develop a first-order approximation of the scale restoration using a method such as a P:B ratio (Kneib 2003) or trophic modeling (for example, PSE&G 1999), and then conduct field studies of the replacement habitat to measure actual rates of growth and survival of the species and life stages of concern.
- Based on monitoring results, conduct adaptive management of restoration actions to rescale restoration as needed.

3.5.5 Recommended Elements of a Restoration Proposal

Restoration proposals should include the following information:

- Definition of restoration goals, including identification of the nexus between loss and gain (for example, losses of larvae from entrainment and gains in habitat needed to produce equivalent larvae)
- Estimates of anticipated restoration gains and the basis for estimates (for example, estimated fish production per acre per year)
- Estimated time before ecological benefits will accrue
- Anticipated duration of ecological benefits
- Performance standards (success criteria) for accomplishing restoration goals and monitoring to ensure that performance standards are being met (for example, actual fish production per acre per year from field sampling)
- Adaptive management process to improve performance as needed
- Clearly substantiated cost estimates

3.5.6 Scaling Alternatives When Species Are Not Habitat-Limited

When habitat restoration does not offset entrained fish (for example, for species that are not habitat-limited), restoration can be still scaled based on value equivalence to determine other appropriate trade-offs. For example, VEA can be used to identify restoration alternatives of equal value to the public, regardless of their effect on fish production (Allen et al. 2005a; Lazo et al. 2005).

3.6 Use of Restoration Costs in Cost-Effectiveness and Cost-Benefit Analyses

3.6.1 Cost-Effectiveness Analysis

Understanding the cost to the permit applicant of implementing technology to reduce impingement and entrainment versus the cost to the public to mitigate losses absent the technology is directly relevant to agency decisions about the cost-effectiveness of various technologies that could be required in an NPDES permit. That is, the cost to the public of enough habitat restoration to offset entrainment (without an entrainment-reducing technology) may be of a similar magnitude as the cost to the permit applicant to install an entrainment-reducing technology. If so, then there is considerable agency justification to require the technology, additional to the statutory requirement to install BTA. The U.S. EPA has successfully argued this point as part of its justifications for 316(b) technology requirements in the recent Brayton Point, Massachusetts NPDES permit.

Fish replacement costs have also been used at other sites to estimate the cost to the public of offsetting impingement and entrainment. However, most estimates of fish replacement costs have been based on the costs of raising and stocking hatchery fish (AFS 1993; Southwick and Loftus 2003). The cost of habitat restoration sufficient to offset entrainment provides an ecologically based alternative to estimating replacement costs (Strange et al. 2004b). Although fish stocking has the advantage of quickly restoring fish that are targets of commercial and recreational fishing, hatchery fish are not ecologically equivalent to wild fish and therefore may fail to fully recover all lost services (Meffe 1992; NRC 1996; White et al. 1997). As the American Fisheries Society (AFS) notes, "Hatchery-raised fish may not be of the same quality in terms of survivability, genetic make-up, or ecological services provided compared to wild fish" (Southwick and Loftus 2003). As a result, stocking is often rejected as a restoration option in NRDA cases involving fish kills (Reinharz and Burlington 1996).

A focus on wild fish involves estimating the cost of restoring habitat to the level necessary to offset fish losses through natural production (for example, Strange et al. 2004b; Allen et al. 2005b). Natural production ensures that the resulting fish offset fully both ecological and human use services lost because of entrained fish. It is also consistent with the current emphasis on the habitat needed to support self-sustaining fish populations over the long term (NRC 1996; Myers et al. 2004).

3.6.2 Cost-Benefit Analyses

For expensive technologies that may be required in a NPDES permit, applicants and agencies often perform cost-benefit analyses, primarily to ensure that the cost of BTA is not "wholly disproportionate"[7] to its benefits. Although habitat restoration costs are highly relevant to agency decisions about technology requirements in NPDES permits, it is important to recognize

[7]. "Wholly disproportionate" was the phrase used in hearings for the Seabrook, New Hampshire facility to define a limit on reasonable BTA costs.

that restoration costs are not necessarily equivalent to the value of benefits resulting from the restoration. Likewise, cost-benefit analysis is not the same as cost-effectiveness analysis, and the distinctions are important. From an ecological perspective, the cost of a natural resource is the sum total of the underlying elements required to produce or obtain the resource. From a benefits perspective, the value of a natural resource is the maximum amount one is willing to offer in a voluntary exchange for the resource, where value can be expressed in either ecological or monetary terms (Freeman 1993; Kopp and Smith 1993).

Under some limited circumstances, restoration costs can indicate the value of restoration. For instance, voluntary funding for restoration in the region of the facility could be evidence of economic demand for those restoration actions. The U.S. EPA's *Guidelines for Preparing Economic Analyses* state that the use of replacement cost as a proxy for value may be justified "…when individuals are proven willing to incur such replacement costs, through either their voluntary purchases or their support for public works projects. If so, the value of the service is at least as much as the replacement cost" (U.S. EPA 2000, p. 99). However, even where voluntary restoration has occurred, assumptions about value may require evidence that restoration decisions were not based on economically inefficient influences, such as agency mandates.

Because restoration costs cannot simply be assumed to equal the value of benefits, additional economic analysis may be needed to determine the relationship between restoration costs and restoration benefits. Unfortunately, analyses by permit applicants have been based on an incomplete accounting of benefits compared to a complete accounting of costs. The potential values of forage fish, the vast majority of entrainment losses, are often omitted altogether. Sometimes the indirect use values of forage fish are estimated using simple trophic transfer models to account for their value as food for fishery species (for example, Bingham et al. 2005). However, there is considerable uncertainty associated with these simple approaches. In particular, results are highly dependent on the trophic transfer efficiencies that are used, which can vary substantially among species, locations, and time periods.

No permit applicant, in California or elsewhere, has quantified the non-use values of forage fish. Non-use values are the values people hold for a resource that are independent of their use of the resource. They include so-called "existence" and "bequest" values, that is, the values people hold for simply knowing a resource exists or for knowing that the resource will continue to exist for future generations. There are well-established survey techniques for evaluating the existence and magnitude of non-use values, and there is a growing literature on the non-use values for a variety of natural resources (for example, Carson et al. 2003).

It is sometimes argued that the non-use values of forage fishes are unlikely to be significant (for example, Bingham et al. 2005). However, this is an empirical question that should be addressed with research, such as stated preference surveys. In fact, the U.S. EPA conducted a number of focus groups to explore non-use values for impinged and entrained fish and found that (1) the main motives for reducing impingement and entrainment were existence and bequest values (that is, non-use values); (2) both users and non-users of the affected resources held these values for reducing impingement and entrainment; and (3) focus group participants agreed that all fish

species (including forage fish) play an important role in the affected ecosystems. The focus group results also indicated that the public requires entrainment losses expressed in terms of fish (for example, age 1 equivalents), not larvae, in order to express values. The focus group report provides additional detail on these and other findings (Besedin et al. 2005).

CHAPTER 4: Conclusions

Because of the high cost of preventative technologies and the limited options for reducing entrainment, permitting agencies are likely to continue to face difficult decisions about the best way to protect entrainable species. In cases where restoration is used to offset unavoidable losses, including losses that remain after implementation of BTA, it is essential to use the most reliable data and methods to estimate the costs and benefits of restoration. Unfortunately, most habitat restoration projects, in this and other contexts, are undertaken with little understanding of the efficacy of proposed restoration, including the likely quantity of organisms that will be produced.

When demographic data are limited, the HPF method can provide a reasonable estimate of the entrainable larvae within well-defined SWAs. However, the efficacy of the HPF is limited to enclosed or semi-enclosed water bodies, where the extent of the SWA and larval populations can be reliably determined. For power plants on open coasts, where it is extremely difficult to determine the area over which larvae may disperse, HPF results will have significant, and probably unacceptable, uncertainty. Reducing this uncertainty, requires an understanding of complex coastal hydrodynamics, and the effort and cost do so may not be justified, particularly given the magnitude of uncertainties that likely would remain.

The HPF equates the area within the SWA containing the standing stock of entrained larvae to the amount of replacement habitat needed to offset entrainment losses. By contrast, restoration scaling balances environmental losses and restoration gains. The most accurate scaling requires an estimate of the amount of increase (the rate of change) in fish numbers or biomass caused by the restoration (either enhanced production or preservation of existing production against foreseeable loss) whenever possible.

Also in contrast to restoration scaling, HPF estimates as presently formulated do not account for situations where restoration gains do not reach the anticipated rate of increased production for several years after the start of the restoration. Restoration scaling accounts for the time elements of both losses and gains and expresses losses and gains in terms of present value equivalents.

The best restoration scaling metrics include species-specific measures of the increase in numbers or biomass of the species and life stages of concern in the restored habitat, quantified in terms of recruitment, the addition of new recruits to the population per unit area per unit time, or productivity, the rate of fish biomass production per unit area per unit time. Because estimates of the area to be restored and associated restoration costs may play a critical role in settlement negotiations, it is imperative that restoration scaling is as rigorous as practical, using or developing necessary ecological data. If the scale and costs of restoration are underestimated, permitting conditions may not achieve the goal of resource protection.

Even the most robust scaling techniques currently available include uncertainties that must be accounted for, and any proposal for restoration to offset unavoidable entrainment losses should

include a monitoring program to fill critical data gaps. The best way to improve estimates of the amount of restoration needed to offset entrainment losses at California's coastal power plants, and to increase the probability of restoration success, is to monitor the actual rates of fish production in the types of habitats proposed for restoration. Otherwise, quantitative results will continue to be constrained by the lack of demographic data.

4.1 Recommendations

Based on this study's results, the research team offers the following recommendations.

- When demographic data are limited, use the HPF for power plants located on bays and estuaries only. Estimates for power plants located on open coasts are too uncertain and unreliable to be useful for restoration planning, even with extensive analysis of larval dispersal and ocean currents.
- Use the same metrics for restoration scaling and monitoring.
- Conduct adaptive management of restoration activities to ensure that restoration goals are met.
- Design restoration monitoring to collect data that can reduce uncertainty.
- When habitat restoration does not offset entrainment losses (for example, for species that are not habitat-limited), consider using value equivalency to determine appropriate restoration.
- If fish stocking is proposed as a restoration alternative, require that the facility demonstrate ecological equivalence and the public's *willingness to accept* a stocked species in place of the entrained species or in place of the production of wild fish in natural habitat.

4.2 Benefits to California

The information provided in this report can benefit California regulators, facility operators, and environmental stakeholders in several ways. Results provide guidelines for improving upon the HPF method currently in use to estimate the amount of restoration needed to offset entrainment losses in situations where demographic data are limited. This information, combined with ongoing restoration monitoring that to fill data gaps, will help increase the likelihood of successful restoration actions. Restoration costs that are based on valid restoration scaling will also make it possible to compare the costs of technology to minimize losses with the costs to the public to mitigate losses absent the technology. This is directly relevant to licensing and permitting decisions about cost-effectiveness.

GLOSSARY

AFS	American Fisheries Society
BMP	Best Management Practice
BTA	Best Technology Available
CCA	California Coastal Act
CCC	California Coastal Commission
CDFG	California Department of Fish and Game
CEIC	California Environmental Information Catalog
CEQA	California Environmental Quality Act
CERPI	California Ecological Restoration Projects Inventory
CHRPD	California Habitat Restoration Project Database
CPUE	Catch per Unit Effort
CWA	Clean Water Act
DCPP	Diablo Canyon Power Plant
ETM	Empirical Transport Model
GIS	Geographic Information System
HBGS	Huntington Beach Generating Station
HEA	Habitat Equivalency Analysis
HEP	Habitat Enhancement Program
HPF	Habitat Production Foregone
HRC	Habitat-Based Replacement Cost
km	Kilometer
MBPP	Morro Bay Power Plant
MGD	Million Gallons per Day
MLPP	Moss Landing Power Plant
MPA	Marine Protected Area
MW	Megawatt

NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRDA	Natural Resource Damage Assessment
NRPI	Natural Resource Projects Inventory
P:B	Production:Biomass
PIER	Public Interest Energy Research
PM	Proportional Mortality
RD&D	Research, Development, and Demonstration
REA	Resource Equivalency Analysis
SAV	Submerged Aquatic Vegetation
SCAR	San Clemente Artificial Reef
SONGS	San Onofre Nuclear Power Generating Station
SWA	Source Water Area
U.S. EPA	U.S. Environmental Protection Agency
VEA	Value Equivalency Analysis
WISER	Water Intake Structure Environmental Research

List of Species' Scientific Names

Arrow goby (*Clevelandia ios*)

Bay goby (*Lepidogobius lepidus*)

Black croaker (*Cheilotrema saturnum*)

Blackeye goby (*Rhinogobiops nicholsii*)

Blue rockfish (*Sebastes mystinus*)

Cabezon (*Scorpaenichthys marmoratus*)

California halibut (*Paralichthys californicus*)

Cheekspot goby (*Ilypnus gilberti*)

CIQ gobies – Arrow goby (*Clevelandia ios*), Cheekspot goby (*Ilypnus gilberti*), and Shadow goby (*Quietula y-cauda*)

Clinid kelpfishes (*Gibbonsia* spp.)

Combtooth blennies (*Hypsoblennius* spp.)

Diamond turbot (*Pleuronichthys guttulatus*)

KGB rockfishes – Kelp rockfish (*Sebastes atrovirens*), Gopher rockfish (*Sebastes carnatus*), and Black-and-yellow rockfish (*Sebastes chrysomelas*)

Longjaw mudsucker (*Gillichthys mirabilis*)

Monkeyface prickleback (*Cebidichthys violaceus*)

Northern anchovy (*Engraulis mordax*)

Northern lampfish (*Stenobrachius leucopsarus*)

Pacific herring (*Clupea pallasii*)

Pacific staghorn sculpin (*Leptocottus armatus*)

Painted greenling (*Oxylebius pictus*)

Queenfish (*Seriphus politus*)

Rock crab (*Cancer* spp.)

Rockfishes (*Sebastes* spp.)

Shadow goby (*Quietula y-cauda*)

Smoothhead sculpin (*Artedius lateralis*)

Snubnose sculpin (*Orthonopias triacis*)

Spot (*Leiostomus xanthurus*)

Spotfin croaker (*Roncador stearnsii*)

Staghorn sculpin (*Leptocottus armatus*)

Weakfish (*Cynoscion regalis*)

White (sea) perch (*Phanerodon furcatus*)

White croaker (*Genyonemus lineatus*)

REFERENCES

AFS (American Fisheries Society). 1993. "Sourcebook for Investigation and Valuation of Fish Kills. American Fisheries Society." *Supplement to American Fisheries Society Special Publication* 24.

Allen, K. R. 1971. "Relation between Production and Biomass." *Journal of the Fisheries Research Board of Canada* 28:1572–1581.

Allen, L. G. 1982. "Seasonal Abundance, Composition, and Productivity of the Littoral Fish Assemblage in Upper Newport Bay, California." *Fishery Bulletin* 80:769–790.

Allen, L. G., D. J. Pondella II, and M. H. Horn (eds.). 2006. *The Ecology of Marine Fishes: California and Adjacent Waters*. University of California Press, Berkeley.

Allen II, P. D., D. J. Chapman, and D. Lane. 2005a. "Scaling Environmental Restoration to Offset Injury Using Habitat Equivalency Analysis." In *Integrating Ecologic Assessment of Economics to Manage Watershed Problems*, R. J. F. Bruins and M. Heberlein (eds.). CRC Press, Boca Raton, Florida, 165–184.

Allen II, P. D., R. Raucher, E. Strange, D. Mills, and D. Beltman. 2005b. "The Habitat-Based Replacement Cost Method: Building on Habitat Equivalency Analysis to Inform Regulatory or Permit Decisions Under the Clean Water Act." In *Integrating Ecologic Assessment of Economics to Manage Watershed Problems*, R. J. F. Bruins and M. Heberlein (eds.). CRC Press, Boca Raton, Florida, 401–421.

Barnthouse, L. W., D. L. DeAngelis, and S. W. Christensen. 1979. *An Empirical Model of Impingement Impact*. Publication ORNL/NUREG/TM-290. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Bayley, P. B., and R. A. Herendeen. 2000. "The Efficiency of a Seine Net." *Transactions of the American Fisheries Society* 129:901–923.

Besedin, E., R. Johnston, M. Ransom, and J. Ahlen. 2005. *Findings from 2005 Focus Groups Conducted Under EPA ICR #2155.02*. Abt Associates, Inc., Cambridge, Massachusetts. Memo to Erik Helm, U.S. EPA/OW, October 18, 2005. Available in the docket for EPA's 316(b) rulemaking.

Bingham, M. F., A. F. Mohamed, J. C. Kinnell, L. A. Hostetter, and W. H. Desvousges. 2005. *Benefits Valuation Study for Diablo Canyon Power Plant: Final Report*. Prepared for Pacific Gas and Electric Company. February 21.

Bohnsack, J. A. 1989. "Are High Densities of Fishes at Artificial Reefs the Result of Habitat Limitation or Behavioral Preference?" *Bull. Mar. Sci*. 44:631–645.

Bohnsack, J. A., D. E. Harper, D. B. McClellan, and M. Hulsbeck. 1994. "Effects of Reef Size on Colonization and Assemblage Structure of Fishes at Artificial Reefs Off Southeastern Florida, USA." *Bull Mar Sci* 55:796–823.

Boreman, J., C. P. Goodyear, and S. W. Christensen. 1978. *An Empirical Transport Model for Evaluating Entrainment of Aquatic Organisms by Power Plants*. Publication FWS/OBS-78/90. U.S. Fish and Wildlife Service, Ann Arbor, Michigan.

Boreman, J., C. P. Goodyear, and S. W. Christensen. 1981. "An Empirical Methodology for Estimating Entrainment Losses at Power Plants Sited on Estuaries." *Transactions of the American Fisheries Society* 110:253–260.

CALFED. No date. CALFED Bay-Delta Program. CALFED Program Performance and Tracking. http://calwater.ca.gov/performancetracking/about_program_performance.html.

Carson, R. T., R. C. Mitchell, M. Hanemann, R. J. Kopp, S. Presser, and P. A. Ruud. 2003. "Contingent Valuation and Lost Passive Use: Damages from the Exxon Valdez Oil Spill." *Environmental and Resource Economics* 25(3):257–286.

CCRWQCB (Central Coast Regional Water Quality Control Board). 2004. *Attachment 3* (to Draft Waste Discharge Requirements Order No. R3-2004-0028), *Findings Regarding Clean Water Act Section 316(b) and California Water Code Section 13142.5. Modernized Morro Bay Power Plant*. Central Coast Regional Water Quality Control Board. December 3. CEC (California Energy Commission). 2005. *Issues and Environmental Impacts Associated with Once-Through Cooling at California's Coastal Power Plants*. California Energy Commission Staff Report and Industrial Economics, Inc. Presentation prepared in support of 2005 Environmental Performance Report, Moss Landing Marine Laboratories, June 28, 2005. Available: http://www.energy.ca.gov/2005_energypolicy/documents/2005-06-27+28_workshop/presentations/2005-06-28_CEC_Staff_White_Paper.PDF. Accessed Spring 2007.

Chapman, D. W. 1978. "Production in Fish Populations." In *Ecology of Freshwater Fish Production*, S. D. Gerking (ed.). Blackwell Scientific Publications, Oxford, UK, pp. 5–25.

Cicchetti, G. 1998. "Habitat Use, Secondary Production, and Trophic Export by Salt Marsh Nekton in Shallow Waters." *Dissertation.* The College of William and Mary, Williamsburg, Virginia.

Currin, B. M., J. P. Reed, and J. M. Miller. 1984. "Growth, Production, Food Consumption, and Mortality of Juvenile Spot and Croaker: A Comparison of Tidal and Nontidal Nursery Areas." *Estuarines* 7(4A):451–459.

Davis, N., P. Raimondi, and D. Stone. 2006a. "Huntington Beach Units 3 & 4 Entrainment and Impingement Study Results and Recommended Mitigation." Presentation to the California Energy Commission, September 14, 2006. Available:

http://www.energy.ca.gov/sitingcases/huntingtonbeach/compliance/2006-09-14-CEC_HB_PRESENTATION.PDF. Accessed 2007.

Davis, N., P. Raimondi, R. York, and J. Reinhardt. 2006b. *Huntington Beach Units 3 & 4 Entrainment and Impingement Study Results, Mitigation Options, Staff and Working Group Recommendations, and AES' Response and Objections to the Recommendation*. August 28, 2006. Available: http://www.swrcb.ca.gov/rwqcb8/pdf/AES/2006-09-14_CECANALYSIS.pdf. Accessed 2007.

Dixon, D. A. 1999. *Catalog of Assessment Methods for Evaluating the Effects of Power Plant Operations on Aquatic Communities. Final Report.* Report number TR-112013. Electric Power Research Institute, Palo Alto, California.

Duke Energy. 2000. *Moss Landing Power Plant Modernization Project Testimony*. Document Submitted to Mr. Rick Buell, Siting Project Manager, California Energy Commission, June 8, 2000. State of California, Energy and Resources Conservation and Development Commission, Docket No. 99-AFC-4. Available: www.energy.ca.gov/sitingcases/mosslanding/documents/index.html. Accessed 2007.

Duke Energy. 2002. *Morro Bay Power Plant Modernization Project Habitat Enhancement Program*. Duke Energy Morro Bay LLC, 8/30/02. Available: www.energy.ca.gov/sitingcases/mosslanding/documents/index.html. Accessed 2007.

Energy Resources and Conservation and Development Commission. 2000. Commission "Adoption Order in the Matter of: Application for Certification for the Moss Landing Power Plant Project." Order No. 00-1025-24, October 25, 2000. Docket No. 99-AFC-4. State of California. Available: www.energy.ca.gov/sitingcases/mosslanding/documents/index.html. Accessed 2007.

EPRI (Electric Power Research Institute). 2007. *Assessment of Cooling Water Intake Structure Impacts to California Coastal Fisheries*. Electric Power Research Institute, Palo Alto, California. Available: www.swrcb.ca.gov/npdes/cwa316.html. Accessed 2007.

Foster, M. 2005." Issues and Environmental Impacts Associated with Once-Through Cooling at California Coastal Power Plants." Presentation at State Water Resources Control Board Workshop September 26, 2006, Laguna, California. Available: http://www.swrcb.ca.gov/npdes/docs/wrkshp_laguna2005/pres_mosslandingfoster.pdf. Accessed Spring 2007.

Freeman III, A. M. 1993. *The Measurement of Environmental Resource Values: Theory and Methods.* Resources for the Future, Washington, D.C.

French McCay, D. P., M. Gibson, and J. S. Cobb. 2003." Scaling Restoration of American Lobsters: Combined Demographic and Discounting Model for an Exploited Species." *Marine Ecology Progress Series* 264:177–196.

Grossman, G. D., G. P. Jones, and W. J. Seaman, Jr. 1997. "Do Artificial Reefs Increase Regional Fish Production?" A review of existing data. *Fisheries* 22:17–23.

Hamilton, A. L. 1969. "On estimating annual production." *Limnology and Oceanography* 14:771–782.

Hilborn, R. 1987." Living with uncertainty in resource management." *North American Journal of Fisheries Management* 7:1–5.

Hynes, H. B. N. 1961." The invertebrate fauna of a Welsh mountain stream." *Archives of Hydrobiology* 57:344–388.

Hynes, H. B. N., and M. J. Coleman. 1968. "A Simple Method of Assessing the Annual Production of Stream Benthos." *Limnology and Oceanography* 13:569–573.

Jordan, F., S. Coyne, and J. C. Trexler. 1997. "Sampling Fishes in Vegetated Habitats: Effects of Habitat Structure on Sampling Characteristics of the 1-m^2 Throw Trap." *Transactions of the American Fisheries Society* 126:1012–1020.

Julius, B. 1999. *Discounting and the Treatment of Uncertainty in Natural Resource Damage Assessment.* Technical Paper 99-1, NOAA Damage Assessment and Restoration Program, Silver Spring, Maryland.

Kitts, A., and E. Thunberg. 1998. "Description and Impacts of Northeast Groundfish Fishery Buyout Programs." Northeast Fisheries Science Center Reference Document 98-12. November.

Kneib, R. T. 2003. "Bioenergetics and Landscape Considerations for Scaling Expectations of Nekton Production From Intertidal Marshes." *Marine Ecology Progress Series* 264:279–296.

Kopp, R. J., and V. K. Smith (eds.). 1993. *Valuing Natural Assets: The Economics of Natural Resource Damage Assessment.* Resources for the Future, Washington, D.C.

Lazo, J. K., P. D. Allen II, R. C. Bishop, D. Beltman, and R. Rowe. 2005. "Determining Economic Tradeoffs Among Ecological Services: Planning for Ecological Restoration in the Lower Fox River and Green Bay." In *Integrating Ecologic Assessment of Economics to Manage Watershed Problems*, R. J. F. Bruins and M. Heberlein (eds.). CRC Press, Boca Raton, Florida, 371–400.

MacCall, A. D., K. R. Parker, R. Leithiser, and B. Jesse. 1983. "Power Plant Impact Assessment: A Simple Fishery Production Model Approach." *Fish. Bull. U.S.* 81(3):613–619.

MBC Applied Environmental Sciences and Tenera Environmental. 2005. *AES Huntington Beach L.L.C. Generating Station Entrainment and Impingement Study*. Final Report. Huntington Beach, California.

Meffe, G. K. 1992. "Techno-Arrogance and Halfway Technologies: Salmon Hatcheries on the Pacific Coast of North America." *Conservation Biology* 6:350–354.

Menzie, C. A. 1980. "A Note on the Hynes Method of Estimating Secondary Production." *Limnology and Oceanography* 25:770–773.

Meredith W. H., and V. A. Lotrich. 1979. "Production Dynamics of a Tidal Creek Population of *Fundulus heteroclitus* (Linnaeus)." *Estuar. Coast. Mar. Sci.* 8:99–118.

Montrose Settlements Restoration Program. 2005. *Final Restoration Plan and Programmatic Environmental Impact Statement, and Environmental Impact Report*. Report of the Montrose Settlements Restoration Program, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, National Park Service, California Department of Fish and Game, California Department of Parks and Recreation, and California State Lands Commission.

Morin, A., T. A. Mousseau, and D. A. Roff. 1987. "Accuracy and Precision of Secondary Production Estimates." *Limnology and Oceanography* 32:1342–1352.

Myers, R. A., S. A. Levin, R. Lande, F. C. James, W. W. Murdock, and R. T. Paine. 2004. "Hatcheries and Endangered Salmon." *Science* 303:1980.

Newman, R. M., and F.B. Martin. 1983. "Estimation of Fish Production Rates and Associated Variances." *Canadian Journal of Fisheries and Aquatic Sciences* 40:1729–1736.

NOAA (National Oceanic and Atmospheric Administration). 1997. *Scaling Compensatory Restoration Actions: Guidance Document for Natural Resource Damage Assessment under the Oil Pollution Control Act of 1990*. Prepared by the National Oceanic and Atmospheric Administration Damage Assessment and Restoration Program, Silver Spring, Maryland. December. Available: http://www.darcnw.noaa.gov/scaling.pdf. Accessed Spring 2007.

NOAA (National Oceanic and Atmospheric Administration). 1999. *Discounting and the Treatment of Uncertainty in Natural Resource Damage Assessment*. National Oceanic and Atmospheric Administration. Technical Paper 99-1. Silver Spring, Maryland. Available: http://www.darp.noaa.gov/library/pdf/discpdf2.pdf. Accessed Spring 2007.

NOAA (National Oceanic and Atmospheric Administration). 2006. *Habitat Equivalency Analysis: An Overview*. Prepared by the Damage Assessment and Restoration Program, National Oceanic and Atmospheric Administration, Department of Commerce. March 21, 1995. Revised October 4, 2000 and May 23, 2006. Available: http://www.darp.noaa.gov/pdf/heaoverv.pdf. Accessed Spring 2007.

NOAA (National Oceanic and Atmospheric Administration). 2007. *National Estuaries Restoration Inventory.* National Oceanic and Atmospheric Administration. Available: https://neri.noaa.gov.

NRC (National Research Council). 1996. *Upstream: Salmon and Society in the Pacific Northwest*. National Research Council. Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, Board on Environmental Studies and Toxicology, Commission on Life Sciences. National Academy Press, Washington, D.C.

Ofiara, D. D. 2002. "Natural Resource Damage Assessments in the United States: Rules and Procedures for Compensation from Spills of Hazardous Substances and Oil in Waterways Under U.S. Jurisdiction." *Marine Pollution Bulletin* 44:96–110.

Port of San Diego. 2007. San Diego Integrated Natural Resources Management Plan. Available at: http://www.portofsandiego.org/sandiego_environment/nrmp/nrmptable.asp. Accessed 2007.

Powers, S. P., J. H. Grabowski, C. H. Peterson, and W. J. Lindberg. 2003. "Estimating Enhancement of Fish Production by Offshore Artificial Reefs: Uncertainty Exhibited by Divergent Scenarios." *Marine Ecology Progress Series* 264:265–277.

PSE&G (Public Service Electric and Gas Company). 1999. *Permit Renewal Application NJPDES Permit No. NJ0005622*. Public Service Electric and Gas Company Salem Generating Station. Public Service Electric & Gas Co., Newark, New Jersey.

Quigley, J. T., and D. J. Harper. 2006. "Effectiveness of Fish Habitat Compensation in Canada in Achieving No Net Loss." *Environmental Management* 37:351–366.

Rago, P. J. 1984. "Production Forgone: An alternative Method for Assessing the Consequences of Fish Entrainment and Impingement Losses at Power Plants and Other Water Intakes." *Ecological Modelling* 24:79–111.

Raimondi, P. 2005. *Review of Mirant-Potrero 316B Determination*. September 2, 2005 draft report to the Water Quality Control Board, San Francisco Bay Region.

Raimondi, P. 2006a. *Briefing on the Science, Modeling, and Environmental Effects of Marine Organism Entrainment at Coastal Power Plants*. Informational briefing before the California Coastal Commission, December 13. Available: http://www.coastal.ca.gov/meetings/mtg-mm6-12.html. Accessed 2007.

Raimondi, P. 2006b. The Science of Mitigation. *Presentation at the State Water Resources Control Board Workshop on the Regulation and Impact Assessment of Once-through Cooling Systems of California Coastal Power Plants*, August 21, 2006, Moss Landing, California. Available: http://www.waterboards.ca.gov/academy/html/courses_coastalpp.html. Accessed 2007.

Raimondi, P., G. M. Cailliet, and M. S. Foster. 2005. *Diablo Canyon Power Plant Independent Scientist's Recommendations to the Regional Board Regarding "Mitigation" for Cooling Water Impact*. July 27. Available: http://www.waterboards.ca.gov/rwqcb3/Facilities/Diablo/Diablo.htm. Accessed 2007.

Randall, R. G., and C. K. Minns. 2000. "Use of Fish Production per Unit Biomass Ratios for Measuring the Productive Capacity of Fish Habitats." *Canadian Journal of Fisheries and Aquatic Sciences* 57:1657–1667.

Reinharz, E., and L. B. Burlington. 1996. *Restoration Planning – Guidance Document for Natural Resource Damage Assessments Under the Oil Pollution Control Act of 1990*. Prepared for the National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

Ricker, W. E. 1975. "Computation and Interpretation of Biological Statistics of Fish Populations." *Fisheries Research Board of Canada Bulletin* 191.

Rountree, R. A. and K. W. Able. 1992. "Fauna of Polyhaline Subtidal Marsh Creeks in Southern New Jersey: Composition, Abundance, and Biomass." *Estuaries* 15:171–185.

Rozas, L. P. 1992. "Bottomless Lift Net for Quantitatively Sampling Nekton on Intertidal Marshes." *Marine Ecology Progress Series* 89:287–292.

Rozas, L. P. and T. J. Minello. 1997. "Estimating Densities of Small Fishes and Decapod Crustaceans in Shallow Estuarine Habitats: A Review of Sampling Design with Focus on Gear Selection." *Estuaries* 20(1):199–213.

Southwick, R. I., and A. J. Loftus (eds.). 2003. "Investigation and Monetary Values of Fish and Freshwater Mussel Kills." *American Fisheries Society*, Bethesda, Maryland.

Sperduto, M. B., S. P. Powers, and M. Donlan. 2003. "Scaling Restoration to Achieve Quantitative Enhancement of Loon, Seaduck, and Other Seabird Populations." *Marine Ecology Progress Series* 264:221–232.

Steinbeck, J. 2006a. *Application of APF*. Presented as part of AES's presentation on the Huntington Beach siting case for the 9/14/2006 Business Meeting of the California Energy Commission, September 14, 2006. Available: http://www.energy.ca.gov/sitingcases/huntingtonbeach/compliance/. Accessed 2007.

Steinbeck, J. 2006b. *The Why, When and How of Assessing Impingement and Entrainment Impacts*. Presentation at the State Water Resources Control Board Workshop on the Regulation and Impact Assessment of Once-through Cooling Systems of California Coastal Power Plants, August 21, 2006, Moss Landing, California. Available: http://www.waterboards.ca.gov/academy/html/courses_coastalpp.html. Accessed 2007.

Steinbeck, J., J. Hedgepeth, P. Raimondi, G. Cailliet, and D. Mayer. 2007. *Assessing Power Plant Cooling Water System Impacts*. California Energy Commission. CEC-700-2007-010. Available: http://www.energy.ca.gov/2007publications/CEC-700-2007-010/CEC-700-2007-010.PDF. Accessed 2007.

Strange, E., D. Allen, D. Mills, and P. Raimondi. 2004a. *Research on Estimating the Environmental Benefits of Restoration to Mitigate or Avoid Environmental Impacts Caused by California Power Plant Cooling Water Intake Structures*. Stratus Consulting Inc. California Energy Commission, PIER Energy-Related Environmental Research. 500-04-092. Available: www.energy.ca.gov/pier/final_project_reports/CEC-500-2004-092.html. Accessed 2007.

Strange, E. M., P. D. Allen, D. Beltman, J. Lipton, and D. Mills. 2004b. "The Habitat-Based Replacement Cost Method for Assessing Monetary Damages for Fish Resource Injuries." *Fisheries* 29(7):17–23.

Strange, E. M., H. Galbraith, S. Bickel, D. Mills, D. Beltman, and J. Lipton. 2002. "Determining Ecological Equivalence in Service-to-Service Scaling of Salt Marsh Restoration." *Environmental Management* 29:290–300.

Suter II, G. W. 2005. An ecological risk assessor's view of environmental economics. Foreward to R. J. F. Bruins and M. Heberlein (eds.), *Integrating Ecologic Assessment of Economics to Manage Watershed Problems.* CRC Press, Boca Raton, Florida.

Teal, J. M. and M. P. Weinstein. 2002. "Ecological Engineering, Design, and Construction Considerations for Marsh Restorations in Delaware Bay, USA." *Ecological Engineering* 18:607–618.

Tenera. 2000a. *Diablo Canyon Power Plant 316(b) Demonstration Report*. Prepared for Pacific Gas and Electric Company, San Francisco, California.

Tenera. 2000b. *Moss Landing Power Plant Modernization Project 316(b) Resource Assessment*. Prepared for Duke Energy Moss Landing, LLC, Oakland, California.

Tenera. 2001. *Morro Bay Power Plant Modernization Project 316(b) Resource Assessment*. Prepared for Duke Energy Morro Bay, LLC, Morro Bay, California.

Teo, S. L. H., and K. W. Able. 2003. "Growth and Production of the Mummichog (*Fundulus heteroclitus*) in a Restored Salt Marsh." *Estuaries* 26:51–63.

U.S. EPA (U.S. Environmental Protection Agency). 1977. *Draft Guidance for Evaluating the Adverse Impact of Cooling Water Intake Structures on the Aquatic Environment: Section 316(b) P.L. 92-500*. U.S. Environmental Protection Agency, Office of Water Enforcement, Permits Division, Industrial Permits Branch, Washington, D.C.

U.S. EPA (U.S. Environmental Protection Agency). 2000. *Guidelines for Preparing Economic Analyses.* Report Number 240-R-00-003. U.S. Environmental Protection Agency, Washington, D.C. September.

U.S. EPA (U.S. Environmental Protection Agency). 2004a. *Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule. Chapter 4: Efficacy of Cooling Water Intake Structure Technologies*. EPA 821-R-04-007. U.S. EPA Office of Water, Washington, DC. Available: http://www.epa.gov/waterscience/316b/phase2/devdoc/final.htm. Accessed 2007.

Valiela I., J. E. Wright, J. M. Teal, and S. B. Volkmann. 1977. "Growth, Production and Energy Transformation in the Salt-Marsh Killifish *Fundulus heteroclitus*." *Mar. Biol.* 40:135–144.

Warburton, K. 1979. "Community Structure, Abundance and Diversity of Fish in a Mexican Coastal Lagoon System." *Estuar. Coast. Mar. Sci.* 7:497–519.

Waters, T. F. 1977. "Secondary production in inland waters." In *Advances in Ecological Research*, A. MacFadyen (ed.). Volume 10. Academic Press, New York, 91–165.

Weinstein, M. P. 1983. "Population Dynamics of an Estuarine-Dependent Fish, the Spot (Leisotomus xanthurus) Along a Tidal Creek-Seagrass Meadow Coenocline." *Canadian Journal of Fisheries and Aquatic Sciences* 40:1633–1638.

Weinstein, M. P., and M. P. Walters. 1981. "Growth, Survival and Production of Young-of-Year Populations of *Leiostomus xanthurus* Lacepede Residing in Tidal Creeks." *Estuaries* 4:185–197.

White, R. J., J. R. Karr, and W. Nehlsen. 1997. *Hatchery Report in the Northwest: Issues, Opportunities, and Recommendations.* Report prepared for Oregon Trout, Portland.

Wootton, R. J. 1990. *Ecology of Teleost Fishes*. Chapman & Hall, London, UK.

Yoklavich, M. M., G. Cailliet, J. P. Barry, D. A. Ambrose, and B. S. Antrim. 1991. "Temporal and Spatial Patterns of Abundance and Diversity of Fish Assemblages in Elkhorn Slough, California." *Estuaries* 14:465–480.

York, R., and M. Foster. 2005. *Issues and Environmental Impacts Associated With Once-Through Cooling at California's Coastal Power Plants*. California Energy Commission Staff Report, June 2005. CEC-700-2005-013. Available: http://www.energy.ca.gov/siting/once_through_cooling.html. Accessed 2007.

Appendix A:
Restoration Actions and Restoration Costs

A.1 Restoration Actions for Impinged and Entrained Species

We developed a survey framework to solicit and evaluate the opinions of California fisheries and aquatic habitat restoration experts regarding the types of restoration actions that could increase the production of specific species. The survey was also designed to elicit the respondents' views regarding the relative ability of the different actions to increase the production.

First, this section discusses the criteria that must be met for a given restoration action to increase fish production. Next, it describes the survey device developed to elicit the expert opinions, and the motivation for the survey design. Third, it provides a brief description of the reasons each of the habitat restoration options were selected. Finally, it summarizes the survey outreach and solicitation efforts and results.

A.1.1 Conditions Needed for Habitat Restoration to Increase Fish Production

For an aquatic habitat restoration project to increase fish production, the restored habitat must satisfy at least two critical conditions. First, the habitat must play a critical role at some stage in the species' life history as either a spawning, nursery, refuge, or forage location. Second, the current combination of the quality and quantity of available habitat must be a limiting factor in the species' production. When these conditions are met, there is a reasonable expectation that the restoration action will increase the species' production, all else equal.

A.1.2 Survey Device for Eliciting Expert Opinion

To evaluate whether it is reasonable to expect that implementing a habitat restoration action would increase production of a given species, we surveyed recognized fishery and habitat restoration experts in California. In addition to asking about specific habitat restoration actions, we also asked experts to prioritize actions in terms of their relative potential to increase production. To develop this information we developed an electronic survey form that allowed respondents to simultaneously indicate whether they believed a habitat restoration or other action could increase production and rank those alternatives based on the relative size of the resulting production increases.

Figure A.1 presents an example from the survey form listing the various habitat restoration and other specific actions experts were asked to consider.

Box A.1 provides a copy of the main set of instructions for completing the survey form.

		Alternative actions to increase production of key species entrained by cooling water treatment systems in California Rank in descending order using 1 for the action you think would provide the greatest increase in production and the last, and largest number, for the action you think is likely to provide the smallest production increase. Leave cells blank if you don't think the action would increase production.												
Fish species entrained in California 316b facilities	**Latin name**	**Restore or create submerged aquatic vegetation (SAV) habitat**	**Restore or create giant kelp beds**	**Restore or create salt marsh habitat**	**Restore or create estuarine or bay habitat**	**Restore or create mud flat habitat**	**Restore or create rocky intertidal habitat**	**Restore or create reef habitat**	**Reduce commercial fishing pressure**	**Reduce recreational fishing pressure**	**Improve water quality**	**Create Marine Protected Areas (MPAs)**	**Other (1)**	**Other (2)**
Example species		3		1 (best option, largest production increase)	2			4			5 (option expected to provide the smallest production increase)			
American shad	*Alosa sapidissima*													
Arrow goby	*Clevelandia ios*													
Aurora rockfish	*Sebastes aurora*													
Barcheek pipefish	*Syngnathus exilis*													

Figure A.1. Example from the electronic survey of fisheries and restoration experts on habitat restoration efficacy and priorities

Box A.1. Respondent Instructions for Completing Habitat Restoration Survey

The goal of this exercise is to record your personal opinion with respect to the types of habitat enhancement activities or other actions that could increase the production of the listed species and to prioritize those actions based on your belief as to their relative benefit.

For those species you are familiar with we would appreciate your providing two types of information.

First, we would like you to think about those actions that *could* conceivably increase the production of the identified species based on your knowledge of its life history including spawning and nursery habitats and current sources of environmental pressure (e.g., habitat loss, commercial fishing). A number of alternatives are provided in the columns below, along with room for additional actions that you can specify in the appropriate cell of the *Other* (1) and *Other* (2) columns.

Second, we would like you to rank those actions that you think could increase production of a species by numbering the alternative actions. The numbering will only indicate your views of the relative merits of the alternatives. Number 1 will indicate the option you believe would provide the greatest increase in production, and the largest number will indicate the least effective action.

In the example provided (see the *Example Species* row), we assume there are five actions that could increase the species production. Of these, salt marsh restoration is the action we assume will provide the greatest production increase for this species. In contrast, we assume quality improvements are likely to increase production, but by the smallest amount from among the available options. Options

The *Example Species* row in Figure A.1 indicates how information from multiple respondents could be summarized in terms of the following measures, among other possible options:

The percentage of respondents who indicated the habitat restoration would likely increase the species' production.

The distribution of responses by habitat restoration action or other option in terms of a percentage of all responses identifying an option expected to increase the species' production.

A summary of habitat restoration or other actions that were never identified as having the potential to increase a species' production.

Collectively, these summary results could be used to evaluate whether a consensus habitat restoration action could be identified for a single species or group of species.

A.1.3 Review of the Habitat Restoration Alternatives and Other Options Presented in the Expert Survey

We developed the list of restoration alternatives for the survey using a number of sources, including:

A review of critical habitats identified for California marine fishes (Montrose Settlements Restoration Program 2005; Allen et al. 2006).

References to the habitat restoration as being beneficial for fish or providing important habitat for fish species (for example, Montrose Settlements Restoration Program 2005; NOAA 2007).

Information indicating that the habitat restoration projects or similar actions were being proposed/implemented in California or other areas with a stated goal of projects being implemented in California or elsewhere with the goal of improving fish production or fish stocks in general. In the rest of this section, the specific habitat restoration projects.

A review of the habitat restoration actions being implemented as part of the 316b permit agreement for the San Onofre Nuclear Power Generating Station (SONGS) (Southern California Edison 2007).

Summaries of proposed restoration projects in HPF analyses for select California power plants, for example, Moss Landing (Table 3 and accompanying text by Dr. Pete Raimondi, University of California at Santa Cruz, in Strange et al. 2004a, based on data in Tenera 2000b Morro Bay [CCRWQCB 2004]), Diablo (Raimondi et al. 2005); and Huntington Beach (Davis et al. 2006b).

These sources helped identify the following specific habitat restoration actions that were included in the expert solicitation survey (see Figure A.1):

Restore or create submerged aquatic vegetation (SAV) habitat.

Restore or create giant kelp beds.

Restore or create salt marsh habitat.

Restore or create estuarine or bay habitat.

Restore or create mud flat habitat.

Restore or create rocky intertidal habitat.

Restore or create reef habitat.

In addition to these options, the expert survey included options for reducing commercial or recreational fishing pressure. These options were included because, for some species, reduction in fishing pressures could reduce mortality of spawning females and increase larval supply. For example, a commercial fishing boat buyback project was developed and implemented in the northeast groundfish fishery in an attempt to reduce the mortality pressure from commercial fishing on certain groundfish stocks (Kitts and Thunberg 1998).

Improving water quality was included in the survey in an effort to gauge the perceived importance of water quality as a limiting factor on species production. In most situations, it will not be possible to link and quantify a particular water quality improvement with increased water quality and increased production of a specific species. However, in some circumstances (for example, for small water bodies where impaired water quality is the only or primary stressor and affected populations can be defined) it may be possible to establish these links; at least in a qualitative way.

The establishment of marine protected areas (MPAs) was identified as another possible alternative for increasing production of entrained species. This option is based on the goals of

the California Marine Life Protection Act of 2002, which called for the designation and integrated management of a statewide network of MPAs. Among the explicit goals of the MPAs is to "help sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted" (CDFG 2007). This goal is consistent with efforts to increase production of fish species. Conceptually, MPAs are intended to provide a defined refuge area where, within the boundaries of the MPA, fish will be free from commercial and recreational fishing pressure. If this relief improves spawning success and fecundity by allowing females to mature to later life stages, the MPAs may increase overall production. However there are a number of questions concerning the efficacy of MPAs, and their relatively recent adoption means there is currently a limited and inconclusive body of associated research to address this question. Finally, the *Other (1)* and *Other (2)* options in the survey were included to provide respondents to identify any additional actions they felt should be identified because of their potential to increase species production.

A.1.4 Survey Outreach and Solicitation Efforts

To conduct the survey, we initially contacted individuals with expertise in California fisheries or experience with implementing aquatic habitat restoration projects at a number of agencies and institutions. The organizations these individuals represent included:

California Coastal Conservancy

California Department of Fish and Game (CDFG)

Moss Landing Marine Laboratories

National Oceanic and Atmospheric Administration (NOAA)

U.S. Fish and Wildlife Service.

These organizations and their staffs provided the opportunity to gather information from across California.

A.1.5 Results of Efforts to Identify and Prioritize Habitat Restoration Efforts for Specific Species

Issues with the timing of the survey development and the extensive nature of the information requested have the limited responses received to date, despite overall interest and expressions of willingness to participate in the research. As a result, our current summary of matching potential habitat restoration actions to specific species relies on a summary of the literature that provides indications of species preferences for specific habitats or a reliance on specific habitats at certain life stages. Figure A.2 presents the results of this summary for all species that we have a record of having been entrained at California cooling water intake structures, based on past facility studies.

The results in Figure A.2 carry a number of caveats. First, because the results are drawn from a literature review, it was not possible to develop the relative weighting information that the electronic survey can capture. Further, the listing of species provides no indication of the

frequency of their entrainment at either a specific facility or across facilities in California. Therefore, it is not possible to draw conclusions about the share of the overall entrainment loss at California cooling water intake structures that is covered by the information in this table.

A.2 Restoration Costs

An aquatic habitat restoration project's cost estimate should provide a comprehensive summary of all of the elements that will be required to achieve the project's stated objectives. When available, comprehensive cost estimates can be combined with similarly detailed cost summaries for completed habitat restoration projects to generate a wide range of useful cost information for those considering similar actions (for example, costs per unit of habitat restored, ranges of specific unit costs). However, prospective users of this information face a number of challenges in determining whether available project cost information is truly comprehensive.

This section has two goals. First, to clearly define the elements of a comprehensive cost estimate, along with an approach to help evaluate whether available project cost information is comprehensive. Second, to summarize restoration cost databases for projects that have been proposed or completed in California. Also provided are some conclusions regarding the combination of cost information from multiple restoration projects.

A.2.1 Overview of a Comprehensive Cost Estimate/Summary

A comprehensive cost estimate will include all of the anticipated costs to design, implement, and monitor a project. While available cost information will vary across projects, reflecting differences in the combination of specific activities and reporting requirements, most cost information is organized in terms of a combination of specific types of actions. Elements and activities whose costs should be included are:

Habitat acquisition or access

Project design, evaluation, and permitting

Implementation, including labor, equipment and supplies

Allowance for contingencies[8]

Operations and maintenance

Monitoring

Oversight and administration.

[8]. Contingency costs are unlikely to appear in a cost summary for completed projects.

Key	***A.*** Result developed from the information in the report *AES Huntington Beach L.L.C. Generating Station Entrainment and Impingement Study: Final Report* (MBC Applied Environmental Sciences and Tenera Environmental 2005). ***E.*** Result developed from the information in *The Ecology of Marine Fishes* (Allen et al. 2006). ***P.*** Results initially presented in the 2004 PIER Final Project Report *Research on Estimating the Environmental Benefits of Restoration to Mitigate or Avoid Environmental Impacts Caused by California Power Plant Cooling Water Intake Structures* (Strange et al. 2004a) based on responses from area biologists. ***S.*** Result developed from the information in the report *San Diego Bay Integrated Natural Resources Management Plan* (Port of San Diego 2007).										
Fish species frequently entrained at California power plants	**Restore or create SAV habitat**	**Restore or create giant kelp beds**	**Restore or create salt marsh habitat**	**Restore or create mud flat habitat**	**Restore or create rocky intertidal habitat**	**Restore or create reef habitat**	**Reduce commercial fishing pressure[a]**	**Reduce recreational fishing pressure[a]**	**Improve water quality[a]**	**Create Marine Protected Areas (MPAs)[a]**	**Other (1)**
Bay goby[1, 6, 7]	E, P	P	E, P	E, P	P	P			P	P	
Blackeye goby[1, 6, 7]	P	E, P	P	P	P	E, P			P	P	
Blennies	E, P	P	E, P	E, P	A, E, P, S	A, E, P, S			P		
Cheekspot goby[1, 6, 7]	E, P	P	E, P	E, P	P	P			P	P	
Drums[5, 6, 7]			P	P			P		P	P	
Giant kelpfish[2, 6]	S	E, S				E, S					
Northern anchovy	A, E		A, E	A, E			P		P	P	S (open water)
Queenfish[2]											E (surf zone, pelagic) A (open water, soft bottom 10m-70m) S (demersal unconsolidated sediment)
Rockfish (Blue, Gopher, Grass, Kelp)[6, 7]		E, P			E, P	E, P	P		P	P	
Smoothhead sculpin[3, 6, 7]					E	E			P		P (hatchery)
Spotted kelpfish[2, 6]					E	E					S (unconsolidated sediment)
Striped kelpfish[2, 6, 7]					E	E					
Action Notes	a. These actions were not assessed for their relationship to specific species in The Ecology of Marine Fishes, the AES Huntington Beach report, or the San Diego Bay Integrated Natural Resources Management Plan.										
Species Notes	1. Results from the 2004 PIER report reflect responses for *"Gobies"* and were not distinguished by species. 2. Species not addressed in the 2004 PIER report. 3. Results from the 2004 PIER report reflect responses for "*Sculpins*" and were not distinguished by species. 4. Results from the 2004 PIER report reflect responses for "*Drums croakers*" and were not distinguished by species. 5. Species not addressed in *The Ecology of Marine Fishes*. 6. Species not addressed in The AES Huntington Beach report. 7. Species not addressed in the *San Diego Bay Integrated Natural Resources Management Plan*.										

Figure A.2. Indications of habitat requirements and potentially beneficial habitat restoration actions for select species from available literature

Collectively, the above list of cost categories accounts for all phases of a restoration project, from the design phase through actual implementation and long-term maintenance and monitoring to ensure project performance. Each of these cost categories is discussed below.

Habitat acquisition or access: At a minimum, a restoration project proponent needs to demonstrate legal control or approved access to a site to undertake habitat restoration activities. Acquiring direct ownership of the habitat (for example, through a fee-simple purchase) is the most direct and certain expression of this control. Other options for achieving this control can include obtaining a conservation easement, lease arrangements, or unsecured access guarantees with a willing project sponsor with access to the habitat. The costs for obtaining the habitat and securing access are, for many categories of habitat restoration projects, likely to represent a significant portion of total expenses, and the associated cost needs to be clearly identified in a cost estimate/summary.

Design and permitting: Most habitat restoration projects will require some sort of permit or regulatory review process prior to implementation (for example, CEQA review). Both the project and the permitting process are also likely to require construction, engineering, and or detailed implementation sequencing plans. Depending on the location, type, and complexity of the project, these costs can be significant. If detailed estimates cannot be developed, these costs can still be accounted for with either a lump sum estimate or an estimate based on a percentage of other identified costs (for example, 20 percent of anticipated construction costs).

Implementation: This cost element should summarize all costs associated with labor, equipment, and materials required for the project. These costs should also incorporate any expenses associated with mobilization and demobilization required to bring equipment and material to a project site or to provide actual site access during the active restoration phase of the project.

Allowance for contingencies: An allowance for contingencies should be specifically accounted for. This cost reflects the belief that project proponents should always count on the unexpected and prepare for such a contingency with extra funding. Contingencies often are applied as a percentage of total project costs. The percentage may increase as a function of any combination of factors, such as project complexity and duration; use of relatively new techniques, equipment, or materials; and number of project partners and required degree of coordination. Guidance on developing contingency allocations is provided in a number of cost estimating references (for example, U.S. ACE and U.S. EPA 2000).

Operations and maintenance: Most habitat restoration projects require some level of ongoing effort to ensure anticipated benefits are realized. For some projects these expenses can represent a significant share of lifetime project costs and may be critical to the project's success (for example, dredging a waterway to maintain tidal exchange). Because these expenditures are incurred following the "completion" of most of the initial restoration work and may require a separate source of funding, they should be specifically and separately accounted for in a cost estimate.

Monitoring: Monitoring activities may be a critical element of adaptive management of a project and will generally be required to document (qualitatively and/or quantitatively) project performance. Because these expenditures will occur in future periods after project "completion," and may require separate funding, they should be specifically and separately accounted for in a cost estimate.

Oversight and administration: The project proponent cannot effectively implement a habitat restoration project without providing some level of oversight and administration. The resources in terms of labor and any supplies that are required as part of this effort need to be accounted for.

The value of this cost categorization approach is that key elements of cost estimates are explicit, which helps ensure that all costs are accounted for. A full accounting of costs is critical to project success.

A.2.2 Evaluating Cost Estimates for Habitat Restoration Projects

To ensure that all cost elements are included in a cost estimate for a given project, a number of key questions should be addressed:

Is the project narrative consistent with the available cost information?

Relevance: If the cost estimate is inconsistent with the project narrative, it is likely to underestimate true project costs. For example, if a project description notes the need for significant habitat re-grading or re-contouring, the cost estimate should include costs for actions and equipment consistent with this activity (for example, soil excavation and/or removal).

Are donated or discounted goods and/or services accounted for in the cost information?

Relevance: In many cost estimates there is no accounting of goods and services that were donated or provided at discount. This is required for an accurate reflection of the actual resource commitments required to achieve the project outcomes. Failing to account for these donated goods or services would result in an underestimate of cost if similar discounts or donations cannot be obtained for other projects. For example, many kelp and sub-aquatic vegetation restoration projects rely on scuba divers to harvest and transplant the relevant vegetation. This labor is critical to project implementation, and is often donated by individuals or organizations (for example, dive clubs). In developing a comprehensive cost estimate, the fair market value of such volunteer services should be included.

Do the available costs reflect only the funding commitment from one project partner?

Relevance: Many habitat restoration projects are undertaken as cooperative efforts by combinations of public agencies (for example, CDFG, NOAA) and private individuals and organizations. This can create a situation where project summaries describe the full range of restoration activities, but the costs reflect only the funding commitment from the partner providing the information. Where this occurs, cost estimates will understate the actual project costs.

Have prior expenditures and resource commitments associated with habitat acquisition-access and project permitting and design been accounted for?

Relevance: Costs and resource commitments associated with habitat acquisition-access and project permitting and design can represent a significant share of the total anticipated/realized costs for a restoration project. At the same time, these expenses and resource commitments may be incurred well in advance of the final project implementation. As a result, these costs may be omitted from cost estimates that address remaining actions or summaries that start from the point of physical work to restore the habitat. Failure to account for these prior expenditures will result in an artificially low project cost estimate.

Have anticipated future operations and maintenance expenditures and monitoring costs been accounted for?

Relevance: Because these expenditures will be incurred in the future, after the restoration project has been "completed," they may be omitted from some project cost estimates. This omission will understate the true project costs and, in some cases, may omit consideration of costs that are crucial for ongoing project success and the ability of the project to meet stated goals. This issue could also arise if , following the initial project completion, there is an anticipated transfer of property rights that would involve these future costs being borne by an agency or organization that is not part of the project implementation team.

Does the cost estimate incorporate contingency costs?

Relevance: Incorporating funding to account for unexpected events or issues is a well-recognized element of developing a realistic cost estimate. Provision for contingencies may represent a significant portion of the total cost estimate, especially for more complex projects. A cost summary associated with detailed construction plans that specify quantities of materials and labor, with associated unit costs, may omit a line item for contingencies, as all costs are already incurred. Project cost estimates that do not incorporate contingency funding in the total will understate anticipated costs compared to a comprehensive cost estimate.

Are costs for project administration and oversight accounted for?

Relevance: The costs associated with the labor and any associated goods and services required to administer and oversee a project's development and implementation need to be accounted for to avoid understating true project costs. However, these costs are frequently omitted, especially when existing personnel from public agencies provide these services. In these cases, a common view is that these staff members are just completing part of their recognized job assignment. The importance of accounting for these resources is clear, though, when considering the costs associated with private projects compared to public sector projects.

Do project costs involve non-habitat-related expenditures or expenses that are notable because they are unlikely to be frequently encountered?

It is common that a project narrative provides some description of project goals and implementation activities but only provides a simplified cost estimate, such as "the project will restore X acres of habitat for Y dollars." In such cases it will be difficult, if not impossible, to assess the completeness of the cost estimate without developing additional information.

The most effective means of addressing omitted costs from the list above is to contact the current project manager. Often these discussions will clarify what is not included in the initial cost estimate. Having identified the omission, additional information can be elicited from the project manager, either actual cost estimates or approaches for developing estimates.

A.2.3 Sources of California Aquatic Habitat Restoration Project Summaries

Table A.1 provides a summary of databases that contain information for proposed and completed nearshore habitat restoration projects in California.

As noted in Table A.1, several of these databases provide cost information or include a specific field where cost information can be included. In general, these cost summaries present values with little documentation or listing of sources. Therefore, we recommend that, in general, all such cost estimates be treated as likely underestimates of true project costs until more detail is obtained. These inventories generally provide contact information that should facilitate the next step of contacting a knowledgeable project manager to help better understand the completeness of the cost information presented. For projects of interest that lack cost estimates, the project contact information can be used to begin efforts to develop this information.

An additional benefit of these databases is that they can be used to help identify potential restoration projects in a specific area, or to identify individuals in an area that may be familiar with certain types of habitat restoration projects. Such individuals may also suggest additional information sources.

A.2.4 Combining Cost Information from Multiple Restoration Projects

There is often interest in knowing what an "average" cost for restoring a unit (for example, an acre) of degraded habitat may be. Extreme caution should be used in developing and applying such estimates.

Table A.1. Summary of identified aquatic habitat restoration project databases for California

Database name	Internet location (home)	General description	Information available	Notes
California Environmental Information Catalog (CEIC)	http://gis.ca.gov/catalog/	Allows users to design queries to obtain links to data sources and collections of interest.	CEIC summary form includes the following fields among others: Title Abstract Time period Purpose Date updated Data contact Links can take you directly to more detailed information from the listed organization	To access the query options for natural resource datasets from the homepage do the following: 1. Select *By Resource Type* in the options for *Look for Data* on the left of the page. 2. At next page select *By Keyword* in the *Look for Data* list on the left. 3. At next page select *Natural Resources. Search term options for types of natural resources that are presented include:* Aquatic resources Energy resources Fishery resources Forest resources Genetic resources Mineral resources Natural resource management Nonrenewable natural resources Rangelands Recreation Renewable natural resources Soils Water resources Wildlife resources. 4. Click on resource of interest and additional resource descriptors may appear to help refine a query to return links to datasets of interest. Notable project links include access to the projects in the San Francisco Joint Venture Project Database.

Table A.1. Summary of identified aquatic habitat restoration project databases for California (cont.)

Database name	Internet location (home)	General description	Information available	Notes
California Ecological Restoration Projects Inventory (CERPI) – Natural Resource Projects Inventory (NRPI)	http://www.ice.ucdavis.edu/nrpi/	Provides a searchable database with links to over 6,000 natural resource-related projects in California. Database has links to information in the CEIC, Geofinder, California Digital Atlas, and Google Maps.	Detailed project summary forms from database searches provide information on the following areas among others: Project name Purpose Abstract Time period Funding sources and amount Purpose Project size and methods Date updated Data contact	Searchable field categories presented to the user on the NRPI homepage include: Title Purpose Abstract Funding program Contact person Participant Project date Project type County Resource issue Water quality constituents Habitat Species Best Management Practices (BMPs) photos Control method Multiple field query (full text search). Drop down lists and follow-up questions, depending on field selected, are used to help refine the project search. Examples of habitat descriptors potentially relevant to 316b restoration proposals include *Estuarine, Marine, Saline Emergent Wetland.* The response to searches generally provides a text note describing the project purpose and a link to a more detailed project summary.

Table A.1. Summary of identified aquatic habitat restoration project databases for California (cont.)

Database name	Internet location (home)	General description	Information available	Notes
CALFED: Ecosystem Restoration Program Project Database	http://www.delta.dfg.ca.gov/erpin/dbase_default.asp	See *Notes* field.	See *Notes* field.	Website currently under construction. CALFED project information can also be generated using the Ecosystem Restoration Program Project Locator found at http://www.delta.dfg.ca.gov/erpin/displaymap.asp. This allows for queries to select types of projects that are then mapped with information that can be accessed by clicking on map icons that are generated for the project.

Table A.1. Summary of identified aquatic habitat restoration project databases for California (cont.)

Database name	Internet location (home)	General description	Information available	Notes
California Habitat Restoration Project Database (CHRPD)	http://www.calfish.org/DesktopDefault.aspx	"The CHRPD currently contains data from the CDFG's Fisheries Restoration Grants Program, the CALFED Ecosystem Restoration Program, the National Fish and Wildlife Foundation, the State Coastal Conservancy, the NOAA Restoration Center, the U.S. Fish and Wildlife Service, the California Conservation Corps, and the Cantara Trustee Council." Quote from the CalFish website text that comes up after clicking on the *Restoration Projects* link on the left side of the homepage.	The CalFish website describes the following information being available from the CHRPD: General project types included in the CHRPD Habitat improvement Watershed assessment and planning Watershed organization support Monitoring Land and water right acquisition Education Hatchery projects Data categories Data source(s) Project timeframe Project description Limiting factors addressed by the project Participants (including role and financial contribution) Funding sources Project costs Site-specific data: Site location Land cover Restoration goals Treatment details and quantities Post-project monitoring Land ownership Project performance measures Species affected Final analysis and final report References	Requires using a mapping tool that is accessed by clicking on the link on the left side of the homepage for *Fish Maps* in the section labeled *Fish Data and Maps.*

Table A.1. Summary of identified aquatic habitat restoration project databases for California (cont.)

Database name	Internet location (home)	General description	Information available	Notes
National Estuaries Restoration Inventory	https://neri.noaa.gov/index.htm	Provides a listing of habitat restoration projects in various estuarine habitats around the United States, by location. Search parameters can be defined to narrow the list of projects that are returned.	In the most detailed project summary, the following information is available: Detailed project description and summary Project contact information Summary of the habitat types and acreage restored Project benefits Project partners Project funding	To search the inventory, first click on the *Search the Inventory* link on the homepage. The links under the *Basic Search* heading on the page to search for projects (https://neri.noaa.gov/query_main.html) can be used to search for relevant projects by location. It provides a search by state option or habitat type and pulls up a page with a drop-down menu of habitat types to choose from. If the search for projects is made by habitat type, the resulting list can be sorted by state, by clicking on the *State* header in the table that is returned. Clicking on the project name in the table that is returned moves the user to a more detailed summary that initially presents an expanded project blurb and a summary of the project type, cost, contacts, and project partners. Clicking on the link at the bottom of this summary for *Full Report* takes the user to the most detailed project summary available.
Bay Area Wetland Tracker	http://www.wetlandtracker.org/	Provides a listing of wetland restoration projects in North and South San Francisco Bay.	Accessing the links for the listed projects provides a more detailed summary with the following information: Latitude Longitude Mapped project area Reported project area Project type (for example, restoration) Counties Land owner Project contacts Links to additional files	From the homepage, click on the link labeled *List all projects* on the top right of the page to pull up all the identified projects. Clicking on the name of any project will open a more detailed summary with information beyond the Name, Status, and Total area provided in the list.

Table A.1. Summary of identified aquatic habitat restoration project databases for California (cont.)

Database name	Internet location (home)	General description	Information available	Notes
Southern California Wetlands Recovery Project	http://www.scwrp.org/work_plan.htm		In the more detailed summaries project information includes: Date of last project update Project leads and contacts Project description Estimated cost Summary of funding	The Wetlands Recovery Project provides information on ongoing and completed projects at various levels of detail. To access a short text summary of completed projects, click on the link for *Project Descriptions* under the section header for *Completed Projects* on the left side of the home page. For a summary of ongoing projects, click on the link for *Work Plan Project Descriptions* on the left of the page in the section titled *Overview.* *For a more detailed summary of projects click on the link for WRP Information Station* on the left side of the homepage in the section titled *Related Items. At the next page click on the link for Current and Completed Projects* on the left of the page. In the resulting drop-down menu, the names of the projects in the combined completed and ongoing project databases appear. The Wetlands Recovery Project focuses on projects between the U.S.-Mexican border in the south to Point Conception in the north.

Specifically, cost estimates from multiple projects should be combined only when the values reflect comprehensive estimates that, if appropriate, have been adjusted (that is, discounted) to account for future expenditures. When combining cost estimates to develop summary measures, care must also be taken in how the summary measure is calculated. For example, an average cost per acre of tidal wetland restoration can be calculated by dividing the sum of all estimated costs by the sum of all acres to be restored in the select project groups. Alternatively, an average cost for each project could be initially calculated and then an average of the results could be calculated.

Only in rare cases (that is, when each project has the same average cost) will the results be the same. In addition, the range of unique opportunities, constraints, and requirements that are reflected in comprehensive cost estimates should produce a wide range of "average" costs across restoration projects focused on a specific habitat with a large enough sample. This variability should highlight the sensitivity of restoration costs to site-specific elements that can only be adequately accounted for when considering a potential project by conducting an initial assessment of the site. Finally, project proponents should realize that cost estimates are only one component of determining cost effectiveness. In the case of restoration projects focused on improving the production of fish, information on expected increases in production as a result of the project implementation is needed to calculate accurate measures of a project's cost effectiveness.

References

Allen, L. G., D. J. Pondella II, and M. H. Horn (eds.). 2006. *The Ecology of Marine Fishes: California and Adjacent Waters*. University of California Press, Berkeley.

CCRWQCB (Central Coast Regional Water Quality Control Board). 2004. *Attachment 3* (to Draft Waste Discharge Requirements Order No. R3-2004-0028), *Findings Regarding Clean Water Act Section 316(b) and California Water Code Section 13142.5. Modernized Morro Bay Power Plant*. Central Coast Regional Water Quality Control Board. December 3. Available: http://www.waterboards.ca.gov/centralcoast/Facilities/DukeEnergy/DukeMB.htm. Accessed 2007.

CDFG (California Department of Fish and Game). 2007. *California Marine Life Protection Act: Master Plan for Marine Protected Areas.* Revised Draft. April 13.

Davis, N., P. Raimondi, R. York, and J. Reinhardt. 2006b. *Huntington Beach Units 3 & 4 Entrainment and Impingement Study Results, Mitigation Options, Staff and Working Group Recommendations, and AES' Response and Objections to the Recommendation*. August 28, 2006. Available: http://www.swrcb.ca.gov/rwqcb8/pdf/AES/2006-09-14_CECANALYSIS.pdf. Accessed 2007.

Kitts, A., and E. Thunberg. 1998. "Description and Impacts of Northeast Groundfish Fishery Buyout Programs." Northeast Fisheries Science Center Reference Document 98-12. November.

MBC Applied Environmental Sciences and Tenera Environmental. 2005. *AES Huntington Beach L.L.C. Generating Station Entrainment and Impingement Study*. Final Report. Huntington Beach, California.

Montrose Settlements Restoration Program. 2005. *Final Restoration Plan and Programmatic Environmental Impact Statement, and Environmental Impact Report*. Report of the Montrose Settlements Restoration Program, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, National Park Service, California Department of Fish and Game, California Department of Parks and Recreation, and California State Lands Commission.

NOAA (National Oceanic and Atmospheric Administration). 2007. *National Estuaries Restoration Inventory.* National Oceanic and Atmospheric Administration. Available: https://neri.noaa.gov.

Port of San Diego. 2007. San Diego Integrated Natural Resources Management Plan. Available at: www.portofsandiego.org/sandiego_environment/nrmp/nrmptable.asp. Accessed 2007.

Raimondi, P., G. M. Cailliet, and M. S. Foster. 2005. *Diablo Canyon Power Plant Independent Scientist's Recommendations to the Regional Board Regarding "Mitigation" for Cooling Water Impact*. July 27. Available: http://www.waterboards.ca.gov/rwqcb3/Facilities/Diablo/Diablo.htm. Accessed 2007.

Southern California Edison. 2007. *Power Generation – Marine Mitigation-Kelp Reef Project*. Available: http://www.sce.com/PowerandEnvironment/PowerGeneration/MarineMitigation/KelpReefProject.htm. Accessed 2007.

Strange, E., D. Allen, D. Mills, and P. Raimondi. 2004a. *Research on Estimating the Environmental Benefits of Restoration to Mitigate or Avoid Environmental Impacts Caused by California Power Plant Cooling Water Intake Structures*. Stratus Consulting Inc. California Energy Commission, PIER Energy-Related Environmental Research. 500-04-092. Available: www.energy.ca.gov/pier/final_project_reports/CEC-500-2004-092.html. Accessed 2007.

Tenera. 2000b. *Moss Landing Power Plant Modernization Project 316(b) Resource Assessment*. Prepared for Duke Energy Moss Landing, LLC, Oakland, California.

U.S. ACE (U.S. Army Corps of Engineers) and U.S. EPA (U.S. Environmental Protection Agency). 2000. *A Guide to Developing and Documenting Cost Estimates during the Feasibility Study*. EPA 540-R-00-002. OSWER 9355.0-075. July.