Arnold Schwarzenegger
Governor

RESEARCH ON ESTIMATING THE ENVIRONMENTAL BENEFITS OF RESTORATION TO MITIGATE OR AVOID ENVIRONMENTAL IMPACTS CAUSED BY CALIFORNIA POWER PLANT COOLING WATER INTAKE STRUCTURES

PIER FINAL PROJECT REPORT

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Prepared By:
Stratus Consulting Inc.
Elizabeth Strange, Managing Scientist
Boulder, Colorado
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Prepared For:
California Energy Commission
Public Interest Energy Research (PIER) Program

Gina Barkalow, Project Manager
Contract Manager

Kelly Birkinshaw,
Program Area Team Lead
Energy-Related Environmental Research

Ron Kukulka,
Acting Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert L. Therkelsen
Executive Director

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Preface

The Public Interest Energy Research (PIER) Program 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 PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

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

What follows is the report for the PIER-EA Exploratory Grant contract, Contract Number #500-02-004 – MRA #015-007, conducted by Stratus Consulting Inc. The report is entitled *Research on Estimating the Environmental Benefits of Restoration to Mitigate or Avoid Environmental Impacts Caused by California Power Plant Cooling Water Intake Structures.* This project contributes to the Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's Web site www.energy.ca.gov/pier or contact the Energy Commission at (916) 654-4628.

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Abstract

The report *Research on Estimating the Environmental Benefits of Restoration to Mitigate or Avoid Environmental Impacts Caused by California Power Plant Cooling Water Intake Structures* (1) identifies and evaluates the information needed to develop and implement restoration proposals, and (2) discusses the techniques available to determine the amount of restoration sufficient to offset impingement and entrainment impacts, and other types of environmental harm at electricity generation facilities subject to California Energy Commission review. The report discusses two restoration scaling techniques—the habitat production foregone (HPF) method and the habitat-based replacement cost (HRC) method. These methods determine the amount and cost of habitat restoration that is required to offset losses. In contrast to stocking, the goal of scaling using the HPF and HRC methods is to determine the scale of habitat restoration required to produce organisms that are ecologically equivalent to those that are lost. Results of such assessments will help permitting agencies evaluate the cost and cost-effectiveness of restoration compared to control technologies. Guidelines are proposed for evaluating and implementing restoration proposals, including case-by-case review, cooperative planning and analysis, explicit definition of restoration goals, use of multiple scaling methods, development of ranges of estimates of losses and restoration gains to help account for uncertainty, comparison of restoration and technology costs, and ongoing monitoring of restoration projects to adjust restoration activities as needed. Use of a consistent and systematic planning and review process will greatly improve the ability of regulators and decision makers to develop and prioritize restoration actions.

Keywords: restoration, restoration scaling, impingement, entrainment, benefit-cost analysis

Executive Summary

Introduction

Environmental restoration has been offered by National Pollutant Discharge Elimination Permit (NPDES) seekers as an alternative to expensive technologies to mitigate the impacts of cooling water intake structures, and it has become an increasing priority for a variety of governmental agencies, nongovernmental organizations, and the general public. However, to evaluate restoration proposals, permitting agencies such as the California Energy Commission must determine the extent to which regulatory requirements allow restoration alternatives, the efficacy of practical restoration options, the amount of restoration that is sufficient, and the cost and cost-effectiveness of restoration compared to control technologies.

Purpose

Research on Estimating the Environmental Benefits of Restoration to Mitigate or Avoid Environmental Impacts Caused by California Power Plant Cooling Water Intake Structures focuses on the information needed to evaluate restoration proposals and the techniques available to determine the amount of sufficient restoration in the context of permitting power plant cooling water intake structures (CWISs). This kind of information and analysis is directly relevant in two different contexts important for Energy Commission decisions: (1) determining the type, scale, and cost of actual restoration as mitigation of harm, whether as an alternative or in addition to control technologies, and (2) providing a basis to compare the cost and effectiveness of restoration with other mitigation measures.

Project Objectives

Project objectives were to:

- Identify species and life stages of aquatic organisms in California susceptible to CWISs and of particular public concern.
- Identify restoration actions that would benefit the species of concern.
- Describe methods for scaling restoration to offset impacts and for developing quantitative estimates of the increase in fish and shellfish production that would result from restoration actions.
- Identify data gaps for completing evaluations of the type, scale, and cost of restoration sufficient to offset or mitigate environmental harm caused by CWISs in California, and make recommendations on how to address data gaps.

Project Outcomes

Some key findings of this project include:

- Over 300 species are known to be impinged and entrained at CWISs in California. Because impingement and entrainment monitoring considers only a subset of the affected species, there are many additional species, particularly macroinvertebrates (e.g., crabs, shrimp) that are undersampled (or not sampled at all).

- In many locations (especially estuaries and coastal waters), populations may migrate over long distances and are subject to impingement and entrainment from multiple cooling water intake structures, resulting in potentially significant cumulative impacts. Future studies should consider such impacts, even though cause-and-effect relationships may be difficult to establish.

Restoration options include:

- Habitat-based actions such as restoration or enhancement of submerged aquatic vegetation, tidal wetlands, intertidal mudflats and sloughs, and kelp forests.

- Construction of artificial reefs to benefit reef-dwelling species (e.g., rockfishes) and construction of artificial breakwaters designed to create sheltered embayments to benefit nearshore, shallow-water species (e.g., striped bass).

- Marine reserves and actions to improve water quality.

- Nonhabitat-based restoration actions such as purchase of commercial fishing capacity and development of fish hatcheries.

Restoration proposals should be evaluated in terms of their relevance for the species lost and restoration goals, and their practicality in the context of local physical and regulatory constraints and opportunities.

Once a relevant and practical restoration action is identified, it is necessary to determine the spatial and temporal extent (scale) of actions needed to offset the loss. Scaling encompasses two related activities: (1) defining and evaluating equivalence, and (2) estimating the scale of required implementation.

Two useful scaling methods are the habitat production foregone (HPF) method and the habitat-based replacement cost (HRC) method. Both methods consider impingement and entrainment losses in terms of the habitat needed to produce organisms that are ecologically equivalent to those that are lost.

The HPF method is most useful when there is a lack of species life history data and other information needed to estimate rates of production in restored habitats. When such data are available, the HRC method can provide more accurate estimates of the scale of restoration based on species-specific production rates.

To take into account losses and gains through time, restoration scaling depends on 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 report discusses technical details related to the development of these kinds of ecological scaling metrics.

Conclusions

- To improve the evaluation of impingement and entrainment losses, a standard impingement and entrainment monitoring protocol and standard metrics for quantifying losses should be developed. Currently, different monitoring protocols are used, resulting in varied outcomes and confusion about actual losses.

- To determine restoration gains with greater accuracy and reliability, there is a critical need to conduct more comprehensive studies of the life histories of species impinged and entrained, and of rates of recruitment, population growth, and productivity in both natural and restored habitats.

- Given the many current data gaps, it is important to develop ranges of scaling estimates using multiple scaling methods, or confidence intervals, if possible with available data.

- The cost of restoration actions should be compared to the costs of control technologies to determine the most cost-effective alternatives for minimizing impacts.

- Economic studies of public values for the organisms impinged and entrained are needed to provide a context for evaluating costs of actions to minimize these impacts.

- Guidelines for evaluating and implementing restoration proposals include:

    - conduct a case-by-case review
    - require cooperative planning and analysis
    - develop explicit definitions of restoration goals
    - use multiple scaling methods
    - develop ranges of estimates of impingement and entrainment losses and restoration gains (or confidence intervals, if possible) to help account for uncertainty
    - compare restoration and technology costs
    - conduct ongoing monitoring and adaptive management.

Recommendations

- Place a high priority on conducting updated impingement and entrainment studies using a standard sampling protocol and quantification metrics.

- Conduct local studies of the life history characteristics of species impinged and entrained, particularly forage species that have high ecological value but are less well-studied than species of commercial and recreational importance. Place an emphasis on studies of fish growth and production rather than solely sampling abundance.

- Conduct economic studies to determine the total economic value (both use and nonuse) of species and life stages lost to impingement and entrainment and the economic benefits of reducing those losses.
- Identify available sites for habitat restoration activities that are recommended to benefit impinged and entrained species.
- Evaluate 316(b) restoration options in the context of regional restoration planning.

Benefits to California

The information provided in this report can benefit California regulators, facility operators, environmental stakeholders, and the Energy Commission in several ways. Results provide:

- A comprehensive record of the losses that are currently known, and identification of data needed to parameterize assessment models and scaling methods to help set priorities for future biological studies.
- Information on restoration actions to benefit particular species. Such information can help maximize the benefits of regional restoration planning.
- Information on restoration scaling and cost-effectiveness analysis, which can play an important role in the permit review process and decisions about mitigation requirements.
- Information applicable to restoration planning to address environmental impacts at other kinds of facilities in addition to electric power generators, including hydropower facilities and desalination plants.

Use of a consistent and systematic planning and review process will greatly improve the ability of regulators and decision makers to develop and prioritize restoration actions.

1. Introduction

1.1 Background and Overview

Most U.S. environmental law is designed to accomplish three broad goals: (1) *development and dissemination of information,* including monitoring, planning, reporting, research, and public participation; (2) *prevention of harm,* including permitting, standards, natural resource preservation, and land acquisition and management; and (3) *restoration,* including incident response, remediation, habitat improvement, land management, and recovery of compensatory damages for restoration (Allen et al. 2004a). In California and across the nation, environmental restoration is becoming increasingly important to solve problems that remain despite the initial progress that has been made by the information and prevention arms of environmental law.

Environmental restoration has been offered by National Pollutant Discharge Elimination Permit (NPDES) seekers as an alternative to expensive technologies to mitigate the impacts of cooling water intake structures, and it has become an increasing priority for a variety of governmental agencies, nongovernmental organizations, and the general public. However, to evaluate restoration proposals, permitting agencies such as the Energy Commission must determine the extent to which regulatory requirements allow restoration alternatives, the efficacy of practical restoration options, the amount of restoration that is sufficient, and the cost and cost-effectiveness of restoration compared to otherwise required technologies.

Unfortunately, environmental restoration is often proposed without determining exactly what kind and, critically, exactly *how much* restoration is needed to address the impact. For restoration to serve as a currency for resolving difficult environmental issues, particularly between potential adversaries in permitting decisions and litigation, data and techniques are required to accurately evaluate the type and amount of harm caused by an action, the type and amount of benefit caused by restoration, and the equivalency of restoration gains compared to environmental harm, even when the gains are not exactly the same as the losses.

This report focuses on the information needed to evaluate restoration proposals and the techniques available to determine the amount of sufficient restoration in the context of permitting power plant cooling water intake structures (CWISs). Such information and techniques can be vital to setting policy for restoration in routine permitting, evaluating or proposing specific restoration types, determining restoration goals relative to regulatory goals, scaling restoration for particular facilities, and settling disputed permitting decisions. This kind of information and analysis is directly relevant to Energy Commission decision making in two different contexts: (1) determining the type, scale, and cost of actual restoration as mitigation of harm, whether as an alternative or in addition to control technologies, and (2) providing a basis to compare the cost and effectiveness of restoration with other mitigation measures.

1.1.1 Section 316(b) of the Clean Water Act

All facilities subject to National Pollution Discharge Elimination System (NPDES) requirements pursuant to Section 402 of the Federal Water Pollution Control Act (also known as the Clean

Water Act, or CWA) that withdraw water for cooling using a CWIS are subject to Section 316(b) of the CWA (33 U.S.C. §1326). Section 316(b) 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. Environmental Protection Agency (EPA) defines the term "cooling water intake structure" to mean the total physical structure and any associated constructed waterways used to withdraw cooling water from waters of the United States (U.S. EPA 2004a). The CWIS extends from the point at which water is withdrawn from the surface water source, up to and including the intake pumps. Power plants are the most common facilities with CWISs.

The EPA has interpreted 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). Impingement occurs when organisms are pinned against intake screens or other parts of a CWIS. Entrainment occurs when organisms in the cooling water are drawn into a cooling water system and subjected to thermal, physical, or chemical stresses. Entrained organisms are typically planktonic, either holoplanktonic (organisms that spend their life as plankton, like diatoms or amphipods) or meroplanktonic (organisms having a complex life history involving a planktonic juvenile stage, such as larvae, seeds, or spores).

The phrase "best technology available" (BTA) in CWA Section 316(b) is not defined in the statute, but its meaning is understood in light of similar phrases used elsewhere in the CWA. As discussed in the Federal Register notice for the Phase II rule of the CWA, EPA interprets BTA to mean technology that is "technically available, economically practicable, and cost-effective" (U.S. EPA 2004a).

The State of California Water Quality Control Board and associated regional boards implement Section 316(b) under the federal NPDES program. However, the Energy Commission has the sole authority for certifying the construction and operation of plants with greater than 50-megawatt (MW) capacity, pursuant to the 1974 Warren-Alquist Act (Public Resources Code Section 25000 et seq.).

1.1.2 Section 316(b) Regulatory Development

The EPA's Office of Water is currently developing regulations pursuant to Section 316(b) in accordance with a consent decree, as amended.[1] The original consent decree, filed on October 10, 1995, resulted from a case brought against EPA by a coalition of individuals and environmental groups headed by Riverkeeper, Inc. The Consent Decree provided that EPA was to propose

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[1] California Hydropower Reform Coalition. www.calhrc.org/relicensing/facilities.htm.

regulations implementing Section 316(b) by July 2, 1999, and take final action with respect to those regulations by August 13, 2001.

Under subsequent interim orders (the Amended Consent Decree filed on November 22, 2000, and the Second Amended Consent Decree, filed on November 25, 2002), EPA divided the rulemaking into three phases. The EPA took final action on a rule governing CWISs used by new facilities (Phase I) on November 9, 2001 (66 FR 65255, December 18, 2001). Clarifying amendments to the Phase I regulations were published on June 19, 2003 (68 FR 36749). The EPA is currently evaluating options for responding to a partial remand of the Phase I rule (Riverkeeper, Inc. v. United States Environmental Protection Agency, No. 02-4005, 2nd Cir. February 3, 2004).

On February 16, 2004, EPA took final action on Phase II regulations that apply to: (1) existing utilities (facilities that both generate and transmit electric power), and (2) existing nonutility power producers (facilities that generate electric power but sell it to another entity for transmission) that employ a CWIS and are designed to withdraw 50 million gallons per day or more and that use at least 25% of their withdrawn water for cooling purposes only (69 FR 41576, July 9, 2004). Impingement requirements call for impingement to be reduced by 80% to 95% from uncontrolled levels. Entrainment requirements call for the number of aquatic organisms drawn into the cooling system to be reduced by 60% to 90% from uncontrolled levels. The rule provides several compliance alternatives, such as using existing technologies, selecting additional fish protection technologies (such as screens with fish return systems), and using restoration measures.

In November 2004, EPA proposed regulations under Phase III of the rulemaking governing CWISs used by smaller-flow power plants and facilities in four industrial sectors (pulp and paper making, petroleum and coal products manufacturing, chemical and allied manufacturing, and primary metal manufacturing) (U.S. EPA 2004b). Final action on the Phase III rule is due by June 1, 2006.

1.1.3 CWIS Permits and Restoration

Permitting under both the Warren-Alquist Act and the CWA requires complex technical evaluations of the terms and conditions for locating appropriate sites, and modifying and operating facilities once sited. Such reviews also address requirements of the California Coastal Act (CCA) and the California Environmental Quality Act (CEQA), including mitigation and restoration goals:

- 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).

- The CEQA considers a sequence of measures that includes 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.

As these sections indicate, both the CCA and CEQA consider restoration a component of environmental regulations intended to protect the natural environment.

Recent Section 316(b) Phase I and Phase II regulations indicate that a facility "may implement and adaptively manage restoration measures that produce and result in increases of fish and shellfish" in the watershed where the facility is located "in place of or as a supplement to installing design and control technologies and/or adopting operational measures that reduce impingement mortality and entrainment" (U.S. EPA 2004a). The facility must demonstrate that the proposed restoration measures "alone or in combination with design and construction technologies and/or operational measures, will produce ecological benefits, including maintenance of community structure and function" at a level that is "substantially similar" to the level that would be achieved through compliance with the regulation.

Although restoration is currently an option in lieu of technology implementation, the restoration option as presented in the Phase I regulation was challenged in Riverkeeper, Inc. v. United States Environmental Protection Agency, No. 02-4005 (2nd Cir., February 3, 2004). The court ruled that EPA exceeded its authority by allowing facilities to conduct restoration in lieu of installing technology, and remanded that aspect of the rule. EPA is currently evaluating options for responding to the remand.

1.1.4 Restoration Activities under 316(b)

There is a long history of mitigation and conservation measures in 316(b) permitting. In most cases, mitigation has involved fish stocking. Facilities that have implemented hatchery or stocking programs include Crystal River (Florida), John Sevier (Tennessee), Chalk Point (Maryland), Roseton (New York), Pittsburg and Contra Costa (California), and Pilgrim (New Hampshire). However, there is debate about the suitability of this approach, particularly since the available scientific evidence suggests that hatchery fish typically fail to support self-sustaining populations and have many biological characteristics unlike those of wild fish (Myers et al. 2004; NRC 1996b).

As an alternative to stocking, there is increasing interest in habitat creation and restoration as a means of offsetting impingement and entrainment losses. The Salem facility in New Jersey has undertaken an extensive salt marsh restoration project to address fish losses resulting from facility operations (PSE&G 1999). The project involves restoring diked wetlands and eradicating the invasive common reed *(Phagramites australis)* (Weinstein et al. 1997; Weinstein et al. 2001; Teal and Weinstein 2002).

In California, a mitigation project for the San Onofre Nuclear Generating Station has involved construction of an artificial reef and wetlands restoration. A number of California power plants currently undergoing permit review are pursuing restoration alternatives (e.g., Diablo Canyon and Morro Bay). To assist the Energy Commission in its review of such proposals, this report summarizes research on key factors that are essential to the development of reliable, quantitative estimates of the environmental benefits of restoration to offset impingement and entrainment impacts.

1.2 Project Objectives

This project has four primary objectives:

1. Identify species and life stages of aquatic organisms in California susceptible to CWISs and of particular public concern.
2. Identify restoration actions that would benefit the species of concern.
3. Describe methods for scaling restoration to offset impacts and for developing quantitative estimates of the increase in fish and shellfish production that would result from restoration actions.
4. Identify data gaps for completing evaluations of the type, scale, and cost of restoration sufficient to offset or mitigate environmental harm caused by CWISs in California, and make recommendations for how to address data gaps.

1.3 Report Organization

Section 2 of this report describes the project approach. Section 3 describes project outcomes, including a summary of information about California facilities with a CWIS and the aquatic organisms impacted (Section 3.1); restorations that benefit these species (Section 3.2); a description of techniques for scaling restoration to match impacts (Section 3.3); methods for developing ecological scaling metrics (Section 3.4); scaling examples (Section 3.5); and a discussion of data availability, data issues, and studies needed (Section 3.6). Section 4 presents conclusions and recommendations about how the Energy Commission can use project results to evaluate restoration proposals, inform regulatory decisions, apply restoration scaling methods, address data gaps, and choose sites and facilities where data collections and scaling methods can best be applied.

2. Project Approach

This project was designed to gather information from the scientific literature and California fisheries experts about what restoration actions should be considered and how those actions should be scaled to address environmental harm that may be caused by California facilities subject to certification by the Energy Commission. The focus of the research was impingement and entrainment impacts, but project results are also relevant to other kinds of harm to aquatic organisms that may result from the construction or operation of facilities subject to Energy Commission oversight.

Task 1 was to identify fish and shellfish species and life stages susceptible to CWISs and of greatest public concern. For this task, we reviewed impingement and entrainment monitoring data for 18 California facilities. We also reviewed available information on public values for the species lost, to identify those species of greatest concern.

For Task 2, we identified and reviewed available reports and studies on restoration projects in California, and electronic databases of restoration activities. We also conducted phone interviews with local experts to help determine what restoration actions have been conducted or considered to offset impingement and entrainment losses.

Task 3 involved discussions with local fisheries experts and a review of the scientific literature on the methods and data available for estimating increases in rates of fish and shellfish production in restored habitats. We also conducted an example scaling exercise to illustrate how these methods and data can be used to scale restoration actions.

Task 4 focused on identifying gaps in the biological information needed to scale restoration, and studies needed to address data gaps.

Although we had intended to conduct focus groups to interview local experts, we determined that phone interviews were just as effective and less expensive.

3. Project Outcomes

3.1 California Impingement and Entrainment

3.1.1 California Facilities that Impinge and Entrain Aquatic Organisms

Appendix A provides information on the 23 electric power producers in California that are subject to NPDES and Energy Commission Application for Certification (AFC) review, along with their permit renewal schedule. As indicated in the appendix, most California facilities with a CWIS will undergo review over the next few years.

Increasing interest in desalination has raised concerns about potential impingement and entrainment impacts at these types of facilities (Keene 2003; CCC 2004). Appendix B presents a list of desalination facilities that have been proposed for the California coast (CCC 2004). Several proposals are for co-location with existing power plants (indicated in bold), and are therefore subject to Energy Commission review (California Water Desalination Task Force 2003). At co-located facilities, water for desalination is taken from the return flow of the power plant.

3.1.2 Impingement and Entrainment Monitoring

Impingement monitoring involves sampling impingement screens and catchment areas, counting the impinged fish, and extrapolating the count to an annual basis. Entrainment monitoring involves intercepting a small portion of the intake flow directly in front of the intake, collecting fish by sieving the water sample through nets or other collection devices, counting the collected fish, and extrapolating the counts to an annual basis. In the absence of site-specific studies demonstrating otherwise, 100% mortality of impinged and entrained organisms is generally assumed (U.S. EPA 2004a).

The EPA issued guidance for 316(b) studies in 1977 (U.S. EPA 1977), but the document has not been updated, and there is currently no standard protocol for impingement and entrainment monitoring. This makes it difficult to compare loss rates among species, years, or facilities. As a result, at most existing facilities in California it remains difficult to determine the impact of a power plant CWIS relative to other stressors. At one of the most studied facilities in California, the San Onofre Nuclear Generating Station (SONGS), three different studies produced three different sets of predictions about potential impacts (Ambrose et al. 1996).

Because a detailed study can be expensive, it is important to prioritize facilities for study. The following sections discuss the organisms and facilities in California that are likely to be of greatest concern, and therefore of highest priority for more comprehensive analysis.

3.1.3 Organisms Impinged and Entrained in California

As indicated in Appendix C, over 300 species are known to be impinged and entrained at CWISs in California. The appendix also indicates the recreational, commercial, and forage status of these species. Appendix D provides a list of facility studies that were the source of this information. Because impingement and entrainment monitoring typically considers only a subset of species, there may be many additional species impinged and entrained at California facilities, including many macroinvertebrates that are generally undersampled, if at all.

3.1.4 CWIS Impacts in California of Greatest Concern

Based on our evaluation of the information presented in the studies reviewed (Appendix D), the highest loss rates occur in estuaries, where organism densities are high. The typically abundant egg and larval stages of fish and shellfish species are particularly sensitive to entrainment because of their small sizes and inability to avoid intake currents. Organisms with relatively small adult body sizes, such as anchovies, are also more vulnerable. A number of estuarine facilities in California have received considerable public scrutiny because of concerns over their impacts, including Moss Landing, Morro Bay, SONGS, El Segundo, Pittsburg, and Contra Costa.

However, interpreting the ecological significance of high loss rates depends on considering the spatial extent of the area where these species are at risk. This is particularly difficult at ocean facilities such as Diablo. Even in estuaries, where populations are more concentrated, extensive field observations and hydrodynamic modeling may be required to accurately determine the area at risk. In some cases where such information is available, impacts on local fish stocks have been found to be significant. For example, results of an extensive study in 1989 by the Marine Review Committee on the ecological effects of Units 2 and 3 at the SONGS facility indicated a 13% decrease in the standing stock of queenfish and a 6% decrease in the stock of white croaker over the entire area of entire Southern California Bight (Ambrose et al. 1996).

In California, many estuarine species that are of concern because of their relatively high vulnerability are smaller organisms that are forage for higher order consumers and therefore have high ecological value. Clinid kelpfishes (Clinidae), blackeye goby (*Rhinogobiops nicholsii*), snubnose sculpin (*Orthonopias triacis*), and monkeyface prickleback (*Cebidichthys violaceus*) are among those with the greatest proportional losses. At Morro Bay, proportional losses of forage species are highest for blennies (Blenniidae) and goby species (Gobiidae).

Organisms with high commercial and recreational value that are lost in relatively high numbers include California halibut (*Paralichthys californicus*), jacksmelt (*Atherinopsis californiensis*), queenfish (*Seriphus politus*), and white croaker (*Genyonemus lineatus*).

At the Pittsburg and Contra Costa facilities in northern California, special status species such as delta smelt (*Hypomesus transpacificus*) are lost (Southern Energy Delta, LLC 2000). Such species also have high value because of their rarity, as indicated by their listing for special protection under the state and/or federal Endangered Species Act. Delta smelt and other special status species in the Bay-Delta estuary are small-bodied, and therefore particularly vulnerable to entrainment if they are distributed near facility intakes.

In addition to evaluating impacts of single facilities over a few years, it is important to consider potential cumulative impacts. The concept of cumulative impacts refers to the temporal and spatial accumulation of changes in ecosystems, which can be additive or interactive. Cumulative impacts can result from the combined effects of multiple facilities located within the same water body or from individually minor but collectively significant impingement and entrainment impacts taking place over many years. In many locations (especially estuaries and coastal waters), species migrate over long distances and are subject to impingement and entrainment from many CWISs. The Central Coast has three large facilities in close proximity to each other (Diablo Canyon, Morro Bay, and Moss Landing), and researchers are currently considering how their cumulative impacts can be evaluated.

3.1.5 Factors Influencing Vulnerability to Impingement and Entrainment

Rates of impingement and entrainment depend on factors related to the location, design, construction, capacity, and operation of a facility's CWIS, species life history characteristics, and the nature of the surrounding aquatic environment (U.S. EPA 2004a). Table 1 presents a partial list of factors that influence impingement and entrainment rates.

Interactions among larval transport and hydrologic processes are complex and an active area of research (Keough and Black 1996). Such interactions are the basis of hydrodynamic models used to predict entrainment rates in the absence of monitoring data (e.g., Boreman et al. 1978, 1981). Hydrodynamic modeling can also be helpful in indicating which biologically productive areas are within the zone of influence of power plant intakes or where there may be significant interactions between intakes and potential restoration sites (e.g., PSE&G 1999).

Table 1. Partial list of CWIS characteristics and ecosystem and species characteristics influencing exposure to impingement and entrainment

CWIS characteristics	Ecosystem and species characteristics
Depth of intake	**Ecosystem characteristics (abiotic environment):**
Distance from shoreline	
Proximity of intake withdrawal and discharge	Source waterbody type (marine, estuarine, riverine, lacustrine) Ambient water temperatures
Proximity to other industrial discharges or water withdrawals	Salinity levels Dissolved oxygen levels
Proximity to an area of biological concern	Tides/currents Direction and rate of ambient flows
Type of intake structure (size, shape, configuration, orientation)	
Through-screen velocity	**Species characteristics (physiology, behavior, life history):**
Presence/absence of intake control and fish protection technologies	Density in zone of influence of CWIS Spatial and temporal distributions (e.g., daily, seasonal, annual migrations)
Water temperature in cooling system	
Temperature change during entrainment	Habitat preferences (e.g., depth, substrate)
Duration of entrainment	Ability to detect and avoid intake currents
Use of intake biocides and ice removal technologies	Swimming speeds Body size
Scheduling of timing, duration, frequency, and quantity of water withdrawal	Age/developmental stage Physiological tolerances (e.g., temperature, salinity, dissolved oxygen)
Type of withdrawal — once through vs. recycled (cooling water volume and volume per unit time)	Feeding habits Reproductive strategy
Ratio of cooling water intake flow to source water flow	Mode of egg and larval dispersal Generation time

3.1.6 Quantification of Impingement and Entrainment

A number of metrics are available for converting impingement and entrainment monitoring data to estimates of the adults that will be lost because of the loss of early life stages, or the fraction of the juvenile population in the source water body that is lost (Dixon 1999). The most common metrics are described below.

Note that these metrics do not consider potential effects of density-dependent compensation. *Compensation* refers to changes in rates of growth, survival, and reproduction resulting from changes in densities that lead to a buffering of adult populations (Rose et al. 2001). As a result of compensation, it is theoretically possible that reduction in numbers of early life stages of aquatic organisms due to entrainment may be offset by increased growth and survival of remaining individuals, so that total population size is unaffected. However, the extent to which this occurs remains an unresolved issue in the evaluation of power plant impacts (Nisbet et al. 1996). Therefore, in the absence of data to demonstrate and quantify compensation, regulators assess potential impacts with methods that do not assume compensation.

3.1.6.1 Individual Loss Metrics

Adult Equivalent Losses. Annual losses can be expressed in terms of a common adult life stage using the equivalent adult model (EAM). The EAM is a method for expressing losses at a given life stage as an equivalent number of individuals at some other life stage, referred to as the age of equivalency (Horst 1975; Goodyear 1978; Dixon 1999). The age of equivalency can be any life stage of interest. The EAM calculation requires life-stage-specific counts of individuals and life-stage-specific mortality rates from the life stage lost to the life stage of equivalence. The cumulative survival rate from the age lost to the age of equivalence is the product of all stage-specific survival rates to that age. The basic equation is:

$$EL = \sum_{i=1}^{I} (S_i \ x \ N_i)$$

where:

EL = estimated equivalent loss in numbers
S_i = expected survival rate from lifestage (i) to the lifestage of equivalence
N_i = number of individuals of lifestage (i) directly lost as a result of power plant operation
I = total number of lifestages (i) directly affected by power plant operations.

Fecundity Hindcasting. Fecundity hindcasting (FH) is a method used to estimate the number of adult females that would have been produced from the larvae lost to entrainment (Tenera 2000a). Counts of entrained larvae are projected backward to a number of eggs, and the number of eggs is then used to estimate the number of female adults that would have produced them. The assumption is that the population is at carrying capacity (equilibrium). Results give an indication of the number of adult females removed from the reproductive population as a result of entrainment. If the sex ratio is 1:1, multiplying this number by 2 yields an estimate of the loss to the total adult population. FH is often less error prone than the EAM, because survivorship estimates are needed for a much briefer time period than for the calculation of adult equivalents. The equation used to calculate FH is:

$$FH = \frac{1}{\overline{F_T}} \sum_{i=1}^{w} \frac{E_{T_i}}{S_i}$$

where:

w = number of weeks the larvae are vulnerable to entrainment
E_{T_i} = estimated total entrainment for the ith weekly survey period ($i = 1,\ldots,$w)
S_i = survival rate from eggs to larvae of the stage present in the ith weekly survey period
$\overline{F_T}$ = average total life time fecundity for females, equivalent to the average number of eggs spawned per female over their reproductive years.

3.1.6.2 Fractional Loss Metrics

Empirical Transport Model. The empirical transport model (ETM) (Boreman et al. 1978, 1981) predicts the annual loss in recruitment resulting from larval entrainment based on the calculation of a conditional mortality rate. In this context, *conditional mortality* refers to the fraction of the larval population that is lost due to entrainment, absent other sources of mortality. Model equations incorporate details of species distributions and the rate and volume of water withdrawal in relation to water circulation within a source water body. Instantaneous entrainment mortality rates are calculated for each cohort (*C*), age (*J*), and life stage (*L*) in each region (*K*) during each model time step, and then these rates are combined into an overall annual conditional mortality rate for a given species, CMR_e:

$$CMR_e = 1 - \sum_{s=1}^{S} R_s \left\{ \prod_{j=0}^{J} \left[\prod_{l=1}^{L} \left(\prod_{k=1}^{K} D_{s+j,k,l} e^{-E_{s+j,k,l} t C_{j,l}} \right) \right] \right\}$$

where:

$E_{s+j,k.}$ = instantaneous entrainment mortality rate for lifestage (*l*) in time step (*s+j*) from region (*k*)
R_s = relative temporal spawning index for each spawning interval (*s*)
$D_{s+j,k.l}$ = proportion of total abundance lifestage (*l*) in model step time (*s+j*) within region (*k*)
$C_{j,l}$ = fraction of cohort in lifestage (*l*) during age (*j*)
t = length of model time step
e = base of natural logarithms (2.71828...)
S = total number of spawning intervals (*s*) in units of the model time step
J = total number of ages (*j*) in units of the model time step
L = total number of lifestages (*l*)
K = total number of regions (*k*).

Data needed to calibrate the ETM include the cooling water withdrawal rate (volume per unit time), the fraction of entrained organisms that are killed, the ratio of the average intake concentration of organisms to their average water body concentration, the volume of the water body, and the distribution of organisms in relation to the intakes (Boreman et al. 1978, 1981). A similar model can be used to estimate conditional impingement mortality (Barnthouse et al. 1979).

Proportional Entrainment and Proportional Mortality. In California, a simplified version of the ETM has been used that is based on estimates of proportional entrainment (PE) and proportional mortality (PM) (Tenera 2000a). PE is an estimate of likelihood of entrainment for an individual. The time unit is typically a day.

$$PE = \frac{N_E}{N_G}$$

where:

N_E = estimated number of larvae entrained during the day, calculated as (estimated density of larvae in the water entrained that day) x (design specified daily cooling water intake volume)
N_G = estimated number of larvae in the study grid that day.

The fraction of larvae entrained from the source population on a given day is then given as the product:

$$PE \times P_S,$$

where:

P_S = the number of larvae vulnerable to entrainment divided by the number of larvae in the source population (Tenera 2000a).

PM is an estimate of the likelihood of entrainment integrated over the period of risk (Tenera 2000a). The estimation of PM requires an estimate of PE as an input. PM is then estimated as:

$$PM = 1 - (1 - PE)^d$$

where d is the period of risk. This period is determined based on the size frequency distribution of individuals entrained, coupled with a length-at-age relationship, usually taken from the scientific literature.

As an example, the larvae of species A may only be entrained between 4 and 12 days of age. If PE = 0.1, then the estimate of $PM = 1 - (1 - 0.1)^8 = 0.5695$, or about 57%.

3.2 Restoration Opportunities in California Relevant to CWIS Impacts

This section describes restoration actions that have been or could be conducted to increase the production of impinged or entrained fish or shellfish in California.

3.2.1 Types of Restoration in California

In this task, we compiled and categorized restoration actions proposed or incorporated in past 316(b) permit reviews, and other potentially appropriate restoration actions identified in California habitat restoration databases. We reviewed information in the following databases:

- California Bay-Delta Authority: descriptions of all ecosystem restoration grants that were funded in the period 2001–2003 http://calwater.ca.gov/Programs/EcosystemRestoration/EcosystemRestorationGrants.shtml.

- California Ecological Restoration Projects Inventory: projects in the following habitat categories: beach and coastal dunes, coastal and interior salt marsh, brackish and fresh water marsh, stream or river channel http://endeavor.des.ucdavis.edu/cerpi/habitatlist.html.
- National Estuaries Restoration Inventory: projects in California https://neri.noaa.gov/class/search_location.jsp.
- The Natural Resource Projects Inventory: project descriptions related to fish species http://www.ice.ucdavis.edu/nrpi.
- Water Resources Center Archives at the University of California, Berkeley: data available from various linked Web sites www.lib.berkeley.edu/WRCA/restoration.html.

We also contacted individuals with experience designing, implementing, and evaluating restoration projects intended to enhance production of marine species. The initial contact was Dr. Peter Raimondi (University of California at Santa Cruz, Department of Ecology and Evolutionary Biology and Long Marine Laboratory), given his experience evaluating habitat restoration proposals that have come before the Energy Commission in 316(b) applications (e.g., San Onofre, Diablo, Morro Bay). Dr. Raimondi was asked to identify additional individuals with similar experience who could provide an overview of the status and possible future trends of coastal habitat restoration projects or other actions that were intended to increase the production of coastal species. Additional contacts included Jack Fancher (U.S. Fish and Wildlife Service) and Bob Hoffman (National Marine Fisheries Service). However, Mr. Hoffman was unavailable during the interview period.

Each contacted individual was provided with project background information and was then asked about the categories of actions they knew had been pursued, evaluated, or considered to increase the production of coastal species in California. The following sections present the actions that were identified.

3.2.1.1 Habitat-Based Actions

Habitat-based restoration actions seek to increase production by improving the quality, amount, or availability of habitats through restoration of degraded habitat, prevention of degradation, or creation of new habitat. The following types of habitat or habitat actions are relevant for impinged and entrained organisms in California:

- submerged aquatic vegetation (SAV) (Fonseca et al. 1999)
- tidal wetlands, intertidal mudflats, and sloughs (Josselyn et al. 1990; Zedler 1996, 2000; Williams and Zedler 1999)
- kelp forests (Ambrose 1994)
- artificial reefs (DeMartini et al. 1994)
- artificial breakwaters designed to create sheltered embayments.

Other habitat-based actions include the development of marine reserves and actions to improve water quality. To establish marine reserves, areas are defined where commercial and recreational fishing is prohibited (Dayton et al. 2000; Palumbi 2001; Roberts et al. 2001; Botsford et al. 2003; Russ et al. 2004).

3.2.1.2 Nonhabitat-Based Actions

Actions to increase fish or shellfish production that do not directly affect specific habitats include:

- purchase of commercial fishing capacity
- development of fish hatcheries.

The purchase of commercial fishing capacity (e.g., license purchases) can increase species populations by preventing the loss of commercially harvested age classes (e.g., French McCay et al. 2003). Stocking of hatchery fish is often used alone or in combination with habitat restoration. Although stocking may provide additional individuals to the local population, there is increasing concern that in many cases stocking may not promote population growth or sustainability, particularly if habitat restoration is not included (NRC 1996a; White et al. 1997). Moreover, because few hatchery fish are saltwater species, stocking is not currently an option for the majority of coastal species lost to impingement and entrainment.

3.2.2 Relevance Criteria for Proposed Restoration Actions

In general, the first step in evaluating a 316(b) restoration proposal is to determine if the proposed actions are likely to increase the production of the species experiencing impingement and entrainment. However, in some cases regulators or local stakeholders may decide that the mix of species is not as important as the magnitude of the increase.

In determining a proposal's relevance, different evaluation criteria are required, depending on whether the proposed action is habitat-based or nonhabitat-based. These differences are discussed in the following sections.

3.2.2.1 Criteria for Determining Relevance of Nonhabitat-Based Actions

Evaluating the relevance of proposed nonhabitat-based actions can be done quickly with readily available data. For example, determining the relevance of a proposed purchase of commercial fishing capacity requires only information as to whether the commercial licenses to be purchased allow the holder to land species experiencing impingement and entrainment. This determination can be made using available data on commercial fishery landings from local National Oceanic and Atmospheric Administration (NOAA) Fisheries offices (e.g., NOAA 2003).

Similarly, the relevance of a stocking proposal can be readily evaluated. Although in principle it may be possible to develop a hatchery for any species, data such as those provided in Southwick and Loftus (2003) can be used to identify those species for which hatcheries have already been developed and are in operation. For this category of action, evidence of an existing operational hatchery for a given species is taken to demonstrate that a proposal to develop a hatchery for the same species in California is relevant.

3.2.2.2 Criteria for Determining Relevance of Habitat-Based Actions

A habitat-based action is relevant if there is evidence that the action will increase the production of the species of concern. This information can come from a combination of published field surveys and unpublished sources (e.g., state agency sampling programs), but it should also be confirmed through consultations with local fisheries experts.

Based on these criteria, Table 2 summarizes the conclusions of local biologists regarding the relevance of the previously identified habitat and nonhabitat-based actions with respect to their potential to increase the production of species/species groups in California that experience impingement and entrainment. The species within each species group are identified in Appendix C.

Table 2. Conclusions of local biologists regarding the habitat and nonhabitat-based actions having the potential to increase production of species/species groups that experience impingement and entrainment in California

	Habitat restoration actions							Nonhabitat-based actions	
Species/ species group	**SAV**	**Tidal wetlands, intertidal mud flats, sloughs**	**Kelp forests**	**Artificial reefs**	**Artificial breakwaters and embayments**	**Marine reserves**	**Improve water quality[a]**	**Reduce commercial fishing pressure[b]**	**Hatchery[c]**
American shad							X		X
Blennies	X	X	X	X	X		X		
Cabezon			X	X	X	X	X	X	
California halibut		X				X	X		
California scorpionfish			X	X	X	X	X	X	
Chinook salmon	X	X					X		X
Commercial sea basses			X	X	X	X	X	X	X
Commercial shrimp	X	X				X	X	X	
Delta smelt	X	X					X		
Drums croakers		X				X	X	X	
Dungeness crab			X	X	X	X	X	X	
Flounders		X				X	X	X	
Forage shrimp	X	X				X	X		
Gobies	X	X	X	X	X	X	X		
Herrings		X					X		X
Longfin smelt		X					X		

Table 2. (continued)

	Habitat restoration actions							Nonhabitat-based actions	
Species/ species group	**SAV**	**Tidal wetlands, intertidal mud flats, sloughs**	**Kelp forests**	**Artificial reefs**	**Artificial breakwaters and embayments**	**Marine reserves**	**Improve water quality**[a]	**Reduce commercial fishing pressure**[b]	**Hatchery**[c]
Northern anchovy						X	X	X	
Pacific herring		X					X		X
Recreational sea basses			X	X	X	X	X		X
Rockfishes			X	X	X	X	X	X	
Sacramento splittail							X		
Salmon	X	X				X	X		X
Sculpins							X		X
Silversides						X	X		X
Smelts							X		
Steelhead	X	X					X		
Striped bass	X	X		X	X	X	X	X	X
Surfperches	X	X		X	X	X	X	X	X

a. It is assumed that all species could potentially experience increased production if water quality were to improve.
b. Species/species groups that could potentially benefit from reduced fishing pressure were determined by examining fisheries landings data (NOAA 2003).
c. Based on information in Southwick and Loftus (2003).

The information in Table 2 can benefit regulators by identifying combinations of species/species groups and habitat actions that are not generally expected or believed to have the potential to increase a species' production. These "negative" results define a mix of scenarios that should draw the regulators' attention and receive additional scrutiny if observed in a proposed alternative to implementing BTA. For example, based on Table 2, regulators should be initially skeptical of a proposal's relevance if it suggests that additional emplacement of artificial reefs would provide increased production of California halibut, as a means to offset impingement and entrainment losses at an existing or proposed facility.

Additional benefits of Table 2 are realized if such combinations are presented in a proposal for a location where regulators have recognized that implementing BTA may not be a relevant option. In this case, the information in Table 2 can help identify other habitat-based or nonhabitat-based actions that may be more relevant for addressing impingement and entrainment losses (e.g., restoration of tidal wetlands, intertidal areas, or sloughs for California halibut).

3.2.3 Criteria for Determining Practicality of Proposed Restoration Actions

The second step in evaluating a 316(b) restoration proposal is to determine the proposal's practicality. Whereas relevance evaluations can largely be completed without regard to site-specific conditions, a practicality evaluation must be evaluated in the context of local physical and regulatory constraints and opportunities. Local conditions will help determine how the project should be implemented. This in turn will affect the project costs.

The recommended evaluation process for compensatory restoration actions for the Oil Pollution Act of 1990 (see Section 4.3 in NOAA 1997) provides helpful evaluation criteria, including applicability, reasonableness of incremental costs, and validity and reliability. Collectively, these considerations aim to identify the project or group of projects that can provide increased species production with the greatest chance of success at the least cost.

For proposed habitat-based actions, the chief technical consideration is whether implementation will require creating new habitat or restoring a degraded one. It is important to consider whether the level of effort and cost are justified, particularly if there are other alternatives that could potentially produce the same mix of species at lower cost. In general, a proposal that involves creating new habitat, as opposed to restoring areas where the habitat formerly existed or exists but in a degraded condition, should receive closer technical scrutiny. This is because habitat creation is likely to introduce additional costs and a higher level of uncertainty.

It is important to compare the costs of implementing proposed restoration actions with the costs for implementing technological alternatives. Because dozens of different species can be lost to impingement and entrainment at any given facility, designing a proposal with a mix of habitat-based and/or nonhabitat-based actions to provide an equivalent increase in the natural production of all species lost can require a substantial level of effort. As the costs associated with such efforts rise, detractors of the proposal may argue that it is too costly. However, such costs should be compared with the estimated costs of implementing BTA, which is the relevant regulatory benchmark for comparison.

Finally, in some locations, there may be additional barriers to implementing specific nonhabitat-based proposals that would eliminate their consideration despite an initial finding of relevance. For example, for proposed reductions in commercial fishing effort through permit purchase and boat buy-back programs to work, a number of market conditions need to exist. Most important, the level of effort in the fishery for the targeted species must be capped, with no excess capacity and a prevention of re-entry. These conditions are critical; if either condition is not met, the presumed reduction in effort may be offset by those with additional capacity in their permits (e.g., additional allowed days at sea that are currently unused) or by the entry of new entities to the market. In other cases, local opposition to the introduction of hatchery fish into otherwise natural systems could pose a significant practical, and potentially legal, barrier.

3.3 Scaling Restoration

Once a relevant and practical restoration action is identified, it is necessary to determine the spatial and temporal extent of actions needed to offset the loss. The loss is typically defined in terms of the resource itself as well as the "services" it provides. The term "services" or "ecosystem services" refers to the physical, chemical, and biological processes through which natural ecosystems support and sustain all life, including human life (Daily 1997; Daily et al. 1997). Examples of services provided by the organisms lost to impingement and entrainment are public use services such as fishing, and ecological services such as the provision of food for species that support fishing activities (Holmlund and Hammer 1999).

Scaling encompasses two related activities: (1) defining and evaluating equivalence, and (2) calculating the scale of required implementation, as discussed below.

3.3.1 Comparing Losses and Gains

Restoration scaling seeks to compare and balance losses and gains, and therefore it is necessary that losses and gains be expressed in terms of a common metric. Depending on the scaling method, either ecological or economic metrics are used. A variety of techniques have been developed that compare losses to gains as resource-to-resource, service-to-service, or value-to-value (NOAA 1997). Examples include resource equivalency analysis (REA), where numbers of organisms lost and gained are compared directly; habitat equivalency analysis (HEA), where habitats lost and gained (or their services) are compared directly; and value equivalency analysis (VEA) or total value equivalency (TVE), where the values of losses and gains are compared (NOAA 1999a; Allen et al. 2004a).

Each of these techniques presents challenges. For instance, REAs must differentiate organism losses and gains targeted by the analysis from population fluctuations caused by other factors such as emigration and immigration. HEAs must convert acreage of habitat into percentages of services lost or gained, except where habitats are completely destroyed by impacts and created new by restoration, and ecosystem functions are usually very complex and inadequately described in the literature. VEAs or TVEs allow trades between any goods or services that can be valued, but exchanges of extremely dissimilar commodities may be inappropriate under statutes, regulations, agency mandates, or public expectations (e.g., popular amusement parks may be inappropriate substitutes for lost natural resources, even if the economic values are similar). Such scaling requires economic surveys of public values.

The best or easiest scaling metrics can vary among and between various types of losses and gains. Therefore, methods of comparison must be able to rely on a variety of metrics such as numbers, density, or biomass of organisms; amount of habitat; amount of ecological or human services; value; and cost.

In many cases, there are multiple approaches that could be undertaken to compares losses with gains, and the final decision about which techniques to use can be influenced by the context of applicable statutes and mandates, the type of data that exist or could be collected practically, and the similarity of data about losses to the data about gains. In some cases, methods can be combined to address particular regulatory circumstances or types of losses and gains.

3.3.2 Equivalency

In many regulatory contexts, the goal of restoration is to replace lost or injured resources with the equivalent of the resources lost, not simply to increase productivity or population size (Kentula et al. 1992). *Equivalency* can be defined in many ways, including:

- ecological equivalence, expressed in terms of
    - abundance equivalence (e.g., 1,000 individuals lost per year requires 1,000 individuals produced per year)
    - biomass equivalence (e.g., production foregone of the individuals lost requires equivalent production gained)
    - habitat equivalence (e.g., type, quality, and extent of habitat lost requires equivalent habitat gained)
- value equivalence (e.g., economic estimate of total value of loss requires compensation with habitat-based and/or nonhabitat-based actions that the public values equivalently).

Ecological equivalence, the focus of this report, refers to the capacity of a restored, enhanced, or created habitat to reproduce the ecological structures and functions of a resource before injury. In such cases, restoration scaling seeks to determine the amount of restoration required to produce an equivalent quantity of the same or comparable resources (NOAA 1997).

In practice, ecological equivalence is difficult to achieve, and there is not necessarily one-to-one equivalence between resources lost and gained (Strange et al. 2002). Restored resources may differ in type, quality, or value (NOAA 1997). For example, a restoration site may never achieve the same rate of production as a natural site. In such cases, if the goal of restoration is to achieve equivalence, it may be necessary to restore more acres of habitat than would be required if productivity was equivalent to that in natural habitats. In the case of fishery resources, hatcheries may not produce fish that are ecologically equivalent to wild fish produced in natural habitats, and therefore restoration through stocking may not produce the equivalent of the resources lost (Strange et al. 2004).

3.3.3 Restoration Trajectory

In addition to determining the spatial extent of habitat restoration, it is important to consider the time scale required. For example, it will take some time for restoration benefits to begin to accrue, often years after the actual restoration activity is completed. In most cases, there will also be some maximum life span of restoration benefits, and a point of maximum benefits. All these features of the recovery trajectory should be taken into account in estimating the temporal extent of a restoration action.

3.3.4 Discounting

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, 1999b; U.S. EPA 2000). In this context, "present value" refers to the value of past or future losses or gains in the present time. Discounting of resource losses and gains with interest rates greater than 0% is consistent with the common economic assumption that people place a greater value on having resources available now than in the future (Olson and Bailey 1981). The formula used to discount losses or gains is:

$$PV = \sum_{t=t_1}^{T} R_t \times d_t$$

where PV is the present value of the stream of losses or gains, t is the time period, t_1 is the year of the loss, T is the last time period, and R_t is a loss or gain realized in time period t (NOAA 1999b). The loss is discounted forward from t_1 to T and the gains are discounted back. The formula for dt, the weight used to convert losses and gains to present value equivalents, is

$$dt = (1 + r)^{t_0 - t}$$

where r is the discount rate. NOAA and other resource agencies generally consider a 3% discount rate a reasonable proxy for the consumer rate of time preference (NOAA 1997, 1999b).

Note that discounting is not necessary for resource injuries involving continuing losses offset by continuing gains from restoration. Because both losses and gains are exactly offset each year, discounting is not required.

3.4 Methods for Developing Ecological Scaling Metrics

To take into account losses and gains through time, restoration scaling depends on 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 term *primary productivity* refers to rates of production by plants through photosynthesis. *Secondary productivity* refers to rates of production by organisms that obtain energy from organic substances produced by other organisms, including fish and shellfish, the organisms most commonly lost to impingement and entrainment.

Note that in contrast to recruitment and productivity, *standing stock* refers to the abundance or biomass of organisms within a unit area at *a single instant in time* (e.g., number/hectare (ha) or kilogram (kg)/ha). Although a useful descriptor of the current status of a population, standing stock does not take into account rates of population change. Nor does standing stock consider how age and size structure influence these rates. For example, a population of large, slow-growing individuals with low productivity could have the same standing stock as a population of small, young, fast-growing individuals with high productivity (Dixon and Schroeter 1998).

The following sections discuss the primary methods for estimating recruitment and rates of production in restored habitats. This information was assembled through literature review and consultations with California fisheries experts, including Dr. Gregor Cailliet of the Moss Landing Marine Laboratories, Dr. Larry Allen of California State University, Northridge, and Dr. John Dixon of the California Coastal Commission. An unpublished manuscript by Dr. Dixon and his colleague Dr. Stephen Schroeter was particularly helpful (Dixon and Schroeter 1998).

3.4.1 Recruitment and Population Growth

If the goal of restoration is to achieve an increase in population size to offset the numbers of organisms lost, then restoration scaling will focus on recruitment and the rate of population growth. *Recruitment* refers to amount by which a population changes in size over a given interval of time.

Population size is a function of rates of birth, death, immigration, and emigration. A cohort life table developed from population sampling is the basic tool for analyzing this process (Wootton 1990). The life table indicates the stage-specific survival and reproduction of a population.

The information in a cohort life table is used to develop models of population growth. A demographic population model such as a Leslie-matrix-based age-structured model (Caswell 1989) can be used to scale restoration to estimate the number of individuals in each age/size class that will be needed to produce a sufficient number of new recruits to offset the organisms which were lost and the time required for the new recruits to grow into the age/size classes lost (French McCay et al. 2003). For this purpose, it is necessary to know how many individuals in each age/size class are needed to yield new recruits equivalent to the number of individuals that were lost. The EAM (see Section 3.1.6.1) can be used for this purpose.

3.4.2 Productivity

Restoration can also be scaled on the basis of productivity instead of population size. In this case, the interest is production of biomass instead of numbers of individuals. Productivity (usually referred to simply as production) is the rate of change in standing stock biomass per unit area per unit time (e.g., kg/ha/yr) (Wootton 1990). It is the total growth in the weight of the individuals in a population within a unit area over a given time.

The rate of production is a function of the mean growth rate of the individuals in the population and the rate of mortality. Thus productivity over a given interval t_1 to t_2 is given by:

$$P_t = gB$$

where:

$g =$ the mean growth rate of the individuals, measured by the specific growth rate
$B =$ the mean biomass of the individuals within a unit area during the time interval.

The specific growth rate is the instantaneous rate of growth per unit weight:

$$g = (\log_e W_2 - \log_e W_1) / (t_2 - t_1)$$

often expressed as a percent per unit time, $G = 100 \times g$.

Total productivity refers to the sum of somatic production and the biomass of gametes produced (Chapman 1978; Wootton 1990). However, in most cases *production* refers to *somatic production* only.

3.4.3 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). The production foregone for a specified stage, *i*, is calculated as:

$$P_i = \frac{G_i N_i W_i (e^{(G_i - Z_i)} - 1)}{G_i - Z_i}$$

where:

P_i = expected production (pounds) for an individual during stage *i*
G_i = the instantaneous growth rate for individuals of stage *i*
N_i = the number of individuals of stage *i* that are lost (expressed as equivalent losses at subsequent stages)
W_i = average weight (in pounds) for individuals of stage *i*
Z_i = the instantaneous total mortality rate for individuals of stage *i*.

P_j, the production foregone for all individuals lost at stage *j*, is calculated as:

$$P_j = \sum_{i=j}^{t_{\max}} P_{ji}$$

where:

P_j = the production foregone for all individuals lost at stage *j*
$t_{\max}$ = oldest stage considered.

P_T, the total production foregone for individuals lost at all stages j, is calculated as:

$$P_T = \sum_{j=t_{\min}}^{t_{\max}} P_j$$

where:

P_T = the total production foregone for individuals lost at all stages j

$t_{\min}$ = youngest stage considered.

Restoration scaling based on production foregone has included the lost production of affected individuals only (e.g., 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 (e.g., Sperduto et al. 2003).

3.4.4 P:B Ratios

The *production to biomass (P:B) ratio,* also known as the *turnover ratio,* is an index of the rate of production of the individuals within an area per unit of biomass. 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 (Randall and Minns 2000). Multiplication of the P:B ratio by mean biomass provides a measure of production when only biomass is known.

The P:B ratio for a cohort is closely related to the instantaneous growth rate of the cohort (Waters 1977). Given the instantaneous growth rate formula for production:

$$P = GB$$

then

$$G = P/B$$

As a result, a cohort's production can be estimated by measuring the maximum and minimum weight of animals in a cohort, calculating G as ln(maximum weight/minimum weight), and then multiplying G by B, the mean standing stock over the cohort's lifespan (Waters 1977).

It is also possible to estimate P/B based on fish size (Randall and Minns 2000). The equation is:

$$P / B \text{ (per year)} = 2.64 W_{mat}^{-0.35}$$

where:

W_{mat} = weight at maturity.

general, the annual P:B ratio is a function of the number of generations per year. Therefore, ratios are higher for species with multiple generations per year (Waters 1977).

Many factors can cause average P:B ratios to vary among different populations of the same species: (1) the ratio is higher for immature life stages when growth rates are higher; (2) the ratio is lower for populations dominated by older individuals; (3) a population that is expanding shows a higher P:B ratio; and (4) a population that is overcrowded shows a lower ratio (Waters 1977). Mullin (1969), Crisp (1971, 1975), Holme and McIntyre (1971), Waters (1977), Chapman (1978), Banse and Mosher (1980), and Randall and Minns (2000) present summaries of P:B ratios from the literature for fishes and invertebrates.

3.4.5 Use of Abundance as a Proxy for Production

If it can be assumed that 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, and (2) the sampled standing stock is not turned over. 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 an abundance estimate is a reasonable surrogate for annual production.

Abundance can be expressed in terms of individual or fractional losses. Commonly used metrics are described in Section 3.1.6.

Fish sampling data are often reported as catch per unit effort (CPUE), which is the number or weight of fish taken by a defined unit of sampling effort (e.g., number of fish caught per trawl). To use CPUE data to estimate abundance for scaling purposes, it is necessary to determine the habitat category associated with the CPUE data 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.

Assigning CPUE results to a habitat category is typically very straightforward. Generally, the data in a peer-reviewed study have been collected and are presented for a specific habitat type (e.g., SAV, tidal wetlands). In contrast, broad-based sampling programs conducted by state or federal agencies may record the sample catch information by some site identification number without any habitat description. However, through discussions with individuals familiar with the sampling locations, and occasionally through supporting documentation (e.g., annual program summaries), the habitat category of sampled locations can generally be defined.

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 (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 (e.g., use of underwater cameras to record field performance of trawls).

3.4.6 Community-Based Scaling

There is increasing interest in estimating the production of communities rather than single populations. Two methods for estimating rates of community production are given below.

3.4.6.1 Allometric Equation Method

Although originally developed to estimate invertebrate community production, the allometric equation method of Edgar (1990) can also be used to estimate fish community production. An allometric relationship is one in which a physical or physiological property of an organism varies with size. Edgar's (1990) method calculates community production using information on the distribution of size classes and mean daily production rates of individuals in the different size classes.

3.4.6.2 Trophic Modeling

Modeling of energy transfer through food webs is another way to estimate community production. For example, Kneib (2003) developed a simple trophic transfer model to estimate the annual production of fish and shellfish resulting from the annual production of marsh vegetation. A similar approach was used to scale restoration to offset impingement and entrainment at the Salem Nuclear Generating Plant in New Jersey (PSE&G 1999).

3.4.7 Methods for Estimating Secondary Productivity from Field Sampling

3.4.7.1 Cohort Methods

Cohort-based methods for estimating secondary production from field sampling 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). A cohort is a group of individuals of the same age or size class.

Removal Summation. The removal summation method is based on the concept that production by a cohort eventually dies or is otherwise removed (Waters 1977). Therefore, the total mortality of a cohort is equivalent to production for that cohort. There are two basic ways to estimate production by removal summation: the so-called "iteration of apparent loss" approach and independent estimates of removal (Waters 1977).

The first method involves a continuous assessment of the reduction in numbers in a cohort throughout its lifetime. The mean weight of losses is summed over the entire life span to estimate removal, which provides an estimate of total production by the cohort.

$$P_{RS} = \sum_{t=1}^{n} \left[\left(N_t - N_{t+1} \right) \times \left(W_t + W_{t+1} \right) / 2 \right] + \left[N_{t+1} W_{t+1} - N_t W_t \right]$$

where:

N = number of individuals
W = average weight of an individual
t = sample number
n = number of uniformly spaced samples.

If production is based on just two samples, there is an implicit assumption that individual growth and mortality rates are constant over the life of the cohort.

The other removal summation procedure is based on independent estimates of removal. It involves recording separate and independent estimates of all the various forms of mortality and emigration of individuals within the cohort and summing results to estimate total production by the cohort (Waters 1977).

Increment Summation. The increment summation production procedure is similar to the iterative removal summation method (Waters 1977). It 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).

$$P_{IS} = B_1 + \sum_{i=1}^{n(date)-1} \left[\left(D_i + D_{i+1}\right)/2\right] \times \left(W_{i+1} - W_i\right)$$

where:

B_1 = mean biomass on the initial sampling date
$n(date)$ = number of sampling dates
D_i = mean density of individuals at time i
W_i = mean individual weight at time i.

Instantaneous Growth Rate Method. Fish productivity is usually estimated with the instantaneous growth rate method (Ricker 1975). The method 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,

$$P = gB_0\,(e^{g-Z} - 1)\,/\,g - Z$$

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.

Allen's Graphical Method. 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). Production over the interval t_1 to t_2 is given by the shaded area under the curve between w_{t1} and w_{t2}, as indicated in Figure 1.

There are two major sources of error in estimating rates of production using the instantaneous growth rate and Allen curve methods (Chapman 1978): (1) sampling error and possible bias in population and survivorship information (e.g., small or large individuals may suffer selective mortality), and (2) size-specific immigration or emigration.

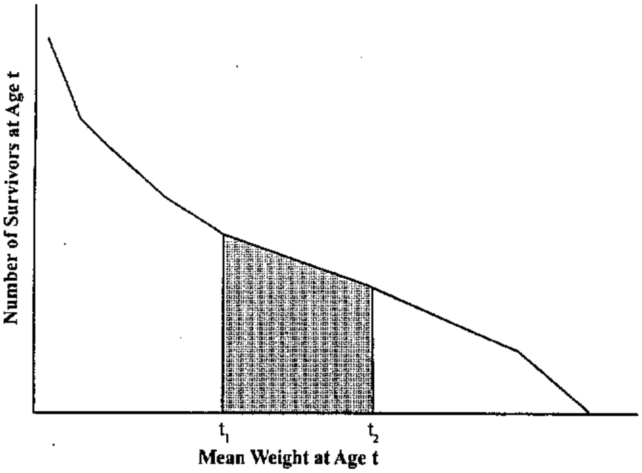

Figure 1. Allen production curve. Hypothetical Allen curve, with shading showing production by the cohort over the period t_1 to t_2. Source: Modified from Wootton 1990.

3.4.7.2 Cohort-Free Size-Frequency Distribution Method

The cohort-free size-frequency method 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). The sampled population is divided into equal-interval size groups, and the mean biomass per individual and mean abundance are calculated for each size group. Then, the change in numbers between size groups is multiplied by the average change in weight per individual between size groups, and the total of all these calculations is summed. The formula is:

$$P = \sum_{j+1}^{i} \left(N_j - N_{j+1}\right) \times \left(W_j \times W_{j+1}\right)^{0.5}$$

where:

P = production over the time period (one year)
i = number of size categories used
j = used to denote each size category, with $j = 1$ composed of the smallest organisms
W_j = mean weight of an individual in the jth size category
N_j = number of individuals that developed into a particular size category during the sampled time period

and where:

$N_i = i \times n_j \times Pe / Pa \times 365 / CPI$ such that i and j are as above and

n = mean number of individuals in size category j
Pe ($= 1/i$) = estimated proportion of the life cycle spent in a particular size category
Pa = actual proportion of the life cycle spent in a particular size category, to correct for nonlinear growth between size categories and the resulting different lengths of time spent in each category
CPI = cohort production interval in days, from hatching until the largest size class is reached, to correct for voltinism.

The size-frequency method has been applied primarily to invertebrates but is considered equally applicable to fish (e.g., Cicchetti 1998).

3.5 Scaling Examples

3.5.1 The HRC Method

The HRC scaling method was originally developed to compare the cost of restored habitats with the cost of preventing losses of organisms to impingement and entrainment. However, it applies to any organism losses. The method and its rationale are discussed in the following sections.

3.5.1.1 The Rationale for HRC in the CWA 316(b) Context

The need for more complete benefit-cost analyses (BCA) for environmental actions was the initial motivation for developing the HRC approach. A BCA requires not only estimates of the costs associated with implementing an action but also monetary measures of the economic benefits of the action. However, the costs of regulatory and permitting actions are usually much easier to measure than the economic benefits of environmental changes. Such benefits can include both *use* values (benefits associated with actively enjoying, using, consuming, or observing environmental resources, e.g., fishing) and *nonuse* values (e.g., *bequest* values tied to enhanced environmental quality for use by others in the future and *existence* values that are not dependent on human use ever occurring) (Freeman 1993).

To prevent systematic bias that may overestimate the cost of a regulatory or permitting action per unit of value, a BCA should measure all values (i.e., the total value), including both use and nonuse values (e.g., U.S. EPA 2000). Although use values are relatively easy to measure on the basis of market goods and services, nonuse benefits are difficult to capture with existing valuation techniques. As a result, BCAs of environmental actions typically include only a small subset of easily measured values, omitting nonuse benefits that may be associated with impacts of greater magnitude. This is particularly apparent in the case of impingement and entrainment, for which the great majority of losses are of forage species with no direct use value.

An extensive body of environmental economics literature demonstrates that the public holds significant value for service flows from natural resources well beyond those associated with direct uses (Fisher and Raucher 1984; Boyd et al. 2001; Fischman 2001; Heal et al. 2001; Herman et al. 2001; Ruhl and Gregg 2001; Salzman et al. 2001; Wainger et al. 2001). Studies have documented public values for the ecological services provided by fish and wildlife (Stevens et al. 1991; Loomis et al. 2000); wetlands (Woodward and Wui 2001); critical habitat for threatened and endangered species (Whitehead and Blomquist 1991; Hagen et al. 1992; Loomis and Ekstrand 1997); shoreline quality (Grigalunas et al. 1988); beaches, shorebirds, and marine mammals (Rowe et al. 1992); and many other natural resources. In many studies, nonuse values account for half or more of the total value (e.g., Fisher and Raucher 1984; McClelland et al. 1992; Kaoru 1993; Hagler Bailly Consulting 1995; U.S. Fish and Wildlife Service and Stratus Consulting 1999, 2000).

Available impingement and entrainment data indicate that only 20 of the over 300 distinct species that are impinged and entrained by California facilities are harvested species with direct market value (NMFS 2002). However, impinged and entrained species provide many other ecosystem services of value to humans. In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to impingement and entrainment are critical to the continued functioning of the ecosystems of which they are a part. Examples of ecological and public services potentially disrupted by impingement and entrainment losses but not addressed by commercial and recreational fishing valuations include (see Peterson and Lubchenco 1997; Postel and Carpenter 1997; Holmlund and Hammer 1999):

- disruption of public uses other than fishing, such as diving and nature viewing
- disruptions of ecological niches and ecological strategies used by aquatic species
- disruptions of organic carbon and nutrient transfer through the food web
- alterations of food web structure
- decreased local biodiversity
- disruption of predator-prey relationships (e.g., Summers 1989)
- disruption of age class structures of species because a disproportionate number of eggs, larvae, and juveniles are lost
- disruption of public satisfaction with a healthy ecosystem.

Many of these services are provided by the early life stages lost to impingement and entrainment, and can be maintained only by the continued presence of these life stages in their natural habitats. For example, aquatic food webs require orders of magnitude more organisms in the lower trophic levels to support harvested species and other top level consumers (Pauly and Christensen 1995).

In the context of BCA, if time and budgetary constraints prevent direct, site-specific total value studies, then expedited approaches such as benefits transfer and replacement costs are sometimes used (e.g., Southwick and Loftus 2003). The HRC method is a replacement cost method based on established scaling methods such as HEA. Courts have determined that under certain circumstances restoration costs constitute a sensible alternative or supplement for use values or "demand-side" measures of the value of natural resources.

The courts have upheld and commented on the advantages of using replacement costs as a measure of damages, pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Marine Sanctuaries Act [United States v. Great Lakes Dredge & Dock Company, 259 F.3d 1300, at 1304 (11th Cir. 2001)], and the oil spill-related provisions of the CWA [State of Ohio v. U.S. Department of Interior, 880 F.2d 432, 444-46, 448, 450, 459 (D.C. Cir. 1989)]. CERCLA states that recovered natural resource damages should be used only to "restore, replace, or acquire the equivalent of such [damaged] natural resources" and that the "measure of damages . . . shall not be limited by sums which can be used to restore or replace such resources" [State of Ohio, 880 F.2d at 444 (quoting 42 U.S.C. § 9607(f)(1)0)]. One court determined that Congress intended that these two clauses be read together, so that restoration costs would not be interpreted as a "ceiling" on damages, even though they would provide the measure of damages in most cases (State of Ohio, 880 F.2d at 444, n. 8, 445-46). The court also noted that any recovery in excess of restoration costs would be directed to acquiring equivalent resources. The court goes on to explain that:

> t]he fatal flaw of Interior's approach [which favored use values over restoration values], however, is that it assumes that natural resources are fungible goods, just like any other, and that the value to society generated by a particular resource can be accurately measured in every case — assumptions that Congress apparently rejected. As the foregoing examination of CERCLA's text, structure and legislative history illustrates, Congress saw restoration as the presumptively correct remedy for injury to natural resources. To say that Congress placed a thumb on the scale in favor of restoration is not to say that it foreswore the goal of efficiency. "Efficiency," standing alone, simply means that the chosen policy will dictate the result that achieves the greatest value to society. Whether a particular choice is efficient depends on *how the various alternatives are valued.* Our reading of CERCLA does not attribute to Congress an irrational dislike of "efficiency"; rather, it suggests that Congress was skeptical of the ability of human beings to measure the true "value" of a natural resource. . . . Congress' refusal to view use value and restoration cost as having equal presumptive legitimacy merely recognizes that natural resources have value that is not readily measured by traditional means. [Emphasis in the original.] (State of Ohio, 880 F.2d at 456–57, and 880 F.2d at 441, 445, 446, n. 13)

The same court also noted that many scholars shared Congress' skepticism concerning our ability to adequately monetize the full value of natural resources. One of these scholars is quoted at some length by the court as follows:

> At first glance, restoration cost appears to be inferior, because it is a cost-based, supply-side measure, rather than a demand-side, value-based measure of natural resource value. For this reason, when natural resource economics advances far enough to provide an adequate demand-side measure, reliance on restoration cost will become inappropriate. At present, however, the economic tools for valuing natural resources are of questionable accuracy . . .. [Using restoration costs as the measure of damages] acknowledges the current ignorance of economic valuation of resources by adopting a cautious, preservationist approach. [Footnote in the original.] (Cross. 1989. *Natural Resource Damage Valuation*, 42 Vand. L. Rev. 269, 331–32.)

3.5.1.2 The Eight Steps of the HRC Method

The HRC method is based on the HEA and REA scaling methods. A HEA assessment balances the loss of habitat and associated services with the creation of additional units and/or improvements in service flows from the same type of habitat. A REA assessment balances losses of organisms with the direct provision of additional organisms. In contrast, an HRC assessment balances organism losses with the amount of habitat needed to produce an offsetting number of organisms and calculates the cost of the restoration. Thus, the HRC method is a hybrid of the REA and HEA approaches.

An HRC analysis has the following main components (as discussed in Allen et al. 2004b and Strange et al. 2004). First, the loss is quantified with a suitable scaling metric (discussed in Section 3.4), and then local resource experts are asked to identify the habitat restoration measures that would be most effective at increasing recruitment or production rates of the organisms lost. Species-specific estimates of expected increases are then developed based on the available scientific literature, supplemented by the expert judgment of local resource managers and restoration experts. Next, the required scale of habitat restoration for each species is estimated by dividing organism losses by the corresponding estimate of gains in the restored habitat. Depending on restoration goals and equivalency criteria, the restoration actions are scaled according to the maximum species estimate, the average of all estimates, or some other appropriate decision rule. Finally, the cost of implementing the required scale of restoration is estimated from similar projects or by restoration experts reflecting the mix of materials and services required to provide the additional habitat or habitat improvements and to monitor the effectiveness of the restoration. These general features of an HRC assessment are captured by the eight steps shown in Figure 2.

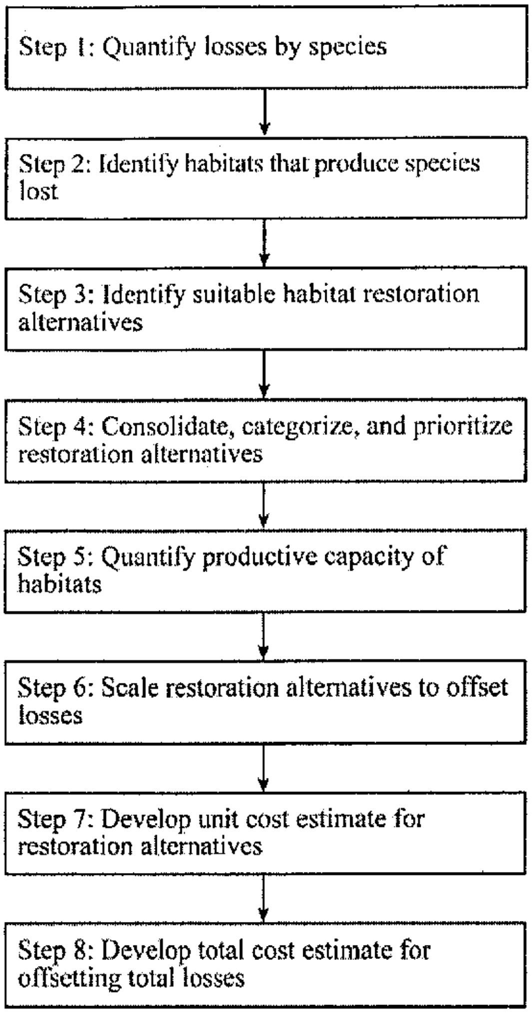

Figure 2. Steps for conducting an HRC analysis.

Completing each of the steps in Figure 2 involves developing and processing different types of information. The following subsections provide additional description for each of the steps.

Step 1. *Quantify Losses by Species*

The first step in an HRC assessment requires quantifying the losses of all life stages of all species (see Section 3.1.6) and expressing these losses in terms of a suitable scaling metric (see Section 3.4). Note that for scaling purposes, the same metric should be used to quantify expected gains as a result of restoration.

This step can be relatively straightforward if organism losses are acute, short-lived, easily measured, and involve a single species and life stage in a confined area. However, this step becomes increasingly complex when multiple species and life stages are involved or if the spatial or temporal extent of the loss is difficult to determine. Impingement and entrainment losses can include hundreds of species and many life stages, including numerous larval stages within the first year of life.

Step 2. *Identify Habitats that Produce Species Lost*

The second step in an HRC analysis involves identifying habitats that produce the species and life stages that are lost. This information is obtained from the scientific literature and discussions with local resource managers, fisheries biologists, and restoration experts.

Step 3. *Identify Suitable Habitat Restoration Alternatives*

The third step in an HRC analysis identifies actual habitat restoration actions that could increase the local production of the organisms lost. The pool of alternatives is restricted only by biological understanding and engineering capability, not by existing funding and administrative constraints. For example, even though there may be little opportunity for local wetland restoration in a location zoned for urbanized development, if local experts consider increasing wetland acreage an effective restoration action, it should be included in the analysis. Note also that it is not necessary for the local population of a species to be habitat-limited as long as creation or restoration of habitat will increase production of the species at the restoration site.

Step 4. *Consolidate, Categorize, and Prioritize Restoration Alternatives*

The fourth step in an HRC analysis involves consolidating and categorizing the restoration alternatives identified in Step 3, and then designating one option for each species as the preferred alternative for that species, based on the best professional judgment of local experts.

Step 5. *Quantify Productive Capacity of Habitats*

The fifth step in an HRC analysis estimates the increases in recruitment or rates of production of each species that are expected to result from implementing the preferred habitat restoration actions. Methods for developing these estimates are discussed in Section 3.4.

Step 6. *Scale Restoration Alternatives to Offset Losses*

In the sixth step of an HRC analysis, the preferred habitat restoration alternatives for each species are scaled so that expected increases offset losses. Dividing the loss by the expected increase over time determines the number of habitat units (and thus the scale) of restoration needed.

In most cases, many species will be involved, and several estimates of the amount of each type of restoration will need to be calculated, because the amount of habitat needed for different species sharing a preferred restoration alternative will vary. In addition, more than one type of restoration will be required to account for all species lost. To ensure that enough habitat is restored to offset losses of each species, the species requiring the greatest scale of implementation will usually determine the level of restoration. Because each species and life stage provide some unique services, the increased production of one species will not necessarily offset the service losses associated with another species.

In some cases, no feasible or practical restorations may be available for a particular species or life stage. In these cases, services or natural resources of equal value to the public can be traded if identical services or resources cannot (see Section 3.3.2).

Step 7. *Develop Unit Cost Estimate for Restoration Alternatives*

The seventh step of an HRC analysis involves estimating unit costs for each of the proposed restoration actions. Costs include anticipated expenses for the design, planning, implementation, administration, maintenance, and monitoring of each restoration action. There should also be a contingency fund to account for unanticipated events that may arise during implementation and monitoring. Unit costs are typically expressed in the same habitat unit as the restoration action by dividing total project costs by the number of habitat units to be restored.

Step 8. *Develop Total Cost Estimate for Offsetting Total Losses*

In the final step of an HRC analysis, the total cost of implementing all restoration actions at the scale necessary to offset the losses of all species is estimated. This involves multiplying the required scale of restoration for each restoration action by its associated unit cost and summing the results, taking care to avoid double counting.

3.5.2 The HPF Method

3.5.2.1 Rationale for the HPF Model

The HPF model was developed to provide an "ecological currency" of loss, where the loss is expressed in terms of the habitat of the organisms at risk. Similar in concept to the HRC, the HPF model is a less complex and data-intensive approach for determining the habitat that is needed to produce the organisms lost.

3.5.2.2 Steps in an HPF Analysis

The HPF model determines impacts to a subset of "target" species based on the idea that losses from environmental impacts can usually be estimated for only a subset of species and that the true impact results from the sum of direct and indirect losses attributable to the impact. An HPF analysis assumes that each targeted species represents a sample, and that the mean of the samples is representative of the true loss rate. Because HPF considers target species to be independent replicates useful for calculating the total expected impact, targeted species are selected to be representative of other species that are either unsampled (most invertebrates, plants or holoplankton) or not targeted for monitoring (the vast majority of fish).

Impacts to target species are estimated in terms of each species' PM, the fraction of larvae at risk that are lost to impingement and entrainment (see Section 3.1.6.2 for a description of the PM calculation). The next step is to take the average PM loss rate for the target species and convert this into an estimate of the amount of habitat from which production is lost. For example, assume that there are five targeted species and calculations indicate that for an estuarine system of 2,000 acres the loss rates for the five species are 5, 10, 3, 22, and 15%. In HPF, the estimate of the total loss would be the average of the five values, or 11%. The area of habitat that would need to be added to the system to offset the lost organisms is then estimated on the basis of the percent loss. Thus, if 11% of organisms at risk in the 2000-acre estuary are lost to entrainment, the HPF estimate of impact would be 2000 acres × 11%, or 220 acres, indicating that 220 acres of restored estuarine habitat would be needed to compensate for the losses, due to entrainment. This does not mean that all biological resources were lost from an area of 220 acres. Instead, it means that if 220 acres of new habitat were created, then all losses, calculated and not calculated, would be compensated for.

Note that this currency of impact (acres needed to compensate) includes all impacts, even indirect ones. A common criticism of the targeted species approach is that nontargeted species are not assessed, and there is no estimation of indirect impacts (such as food web effects). The HPF method addresses these concerns by expressing impact in terms of habitat and assuming that indirect impacts are addressed by the complete compensation of all directly lost resources. In the given example, HPF would predict that the creation of 220 acres of new habitat would compensate for all impacts due to entrainment.

The HPF approach assumes that habitat should be created that represents the habitat for all the populations at risk. If the habitat in the estuary is 60% subtidal eelgrass beds, 15% mudflats, and 25% vegetated intertidal marsh, then these same percentages should be maintained in the created habitat. Doing so ensures that impacts on all affected (not just targeted) species are addressed.

3.5.2.3 Example of Scaling Using the HPF and HRC Methods

The Moss Landing Power Plant (MLPP) withdraws cooling water from the Moss Landing Harbor, which is connected directly to Elkhorn Slough (Figure 3). A 316(b) study was conducted as part of a modernization plan (Tenera 2000b).

Estimates of projected entrainment and PM are shown for targeted species in Table 3. Note that these estimates are only the increases in entrainment that would result from the new units, and do not include estimates of losses from existing units.

In Table 3, ETM^{Avg} refers to estimates of PM that resulted from one of the two possible estimates of the period at risk (see Section 3.1.6.2 for descriptions of these methods). Period at risk is determined from a species-specific calculation of the age distribution of entrained individuals. ETM^{Avg} is an estimate based on the average period at risk. The alternative, ETM^{Max}, is based on the maximum period at risk. In this determination the Regional Water Quality Control Board (RWQCB) presented the range, although scientists employed by the Board advocated using ETM^{Max}, because they felt that the maximum duration represented the true period of risk. In all subsequent determinations only ETM^{Max} has been used.

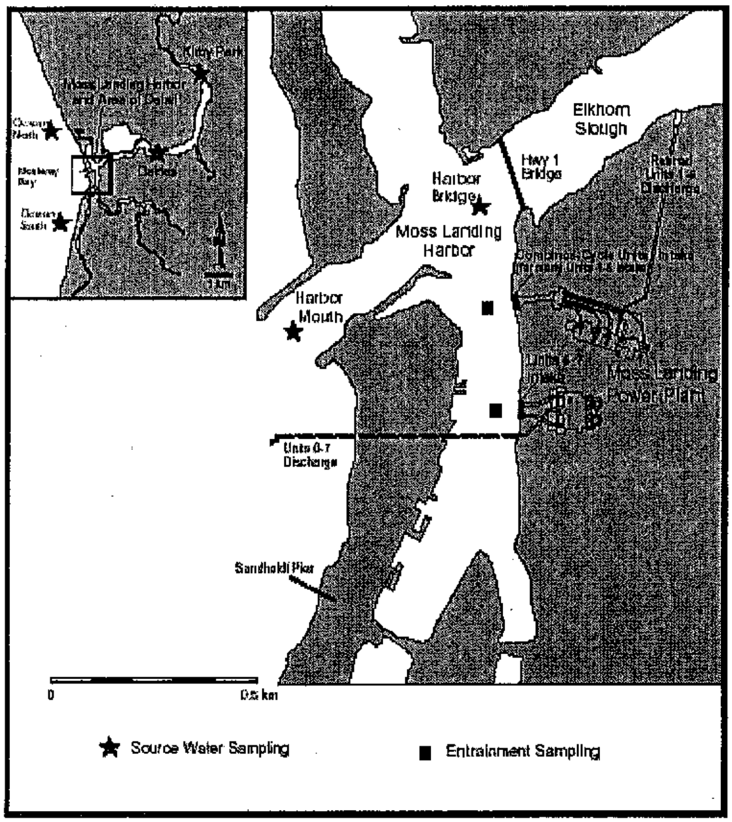

Figure 3. Moss Landing Power Plant. Source: Tenera (2000b).

Table 3. Estimates of projected entrainment and PM for targeted species at Moss Landing

	Total entrainment	FH	Adult equivalent loss	ETM^{Avg}
Unidentified gobies	2.7 x 10^8	300,006	[a]	0.107
Bay goby	1.5 x 10^8	[a]	1,045,588	0.214
Blackeye goby	1.7 x 10^7	1,825	16,636	0.075
Longjaw mudsucker	8.0 x 10^6	497	[a]	0.089
Hypsoblennius spp.	1.7 x 10^7	9,086	10,247	0.182
Pacific herring	4.4 x 10^6	235	243	0.134
White croaker	8.6 x 10^6	107	[a]	0.129
Pacific staghorn sculpin	[a]	[a]	[a]	0.118

a. Indicates that calculation of the metric was not possible because of insufficient survivorship information.

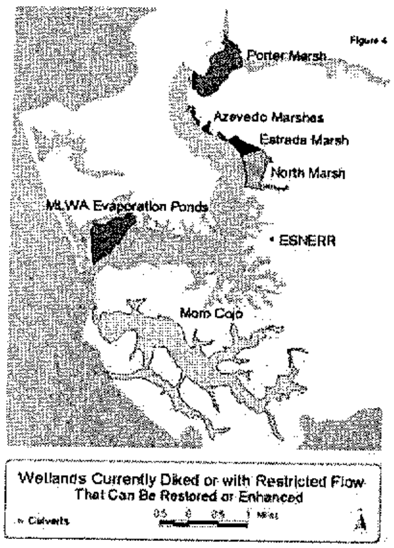

Figure 4. Map of Elkhorn Slough showing potential restoration areas. Colors distinguish different sites. Source: Tenera (2001).

HPF Scaling. The HPF method was used to evaluate these losses. Under the HPF method the target species in Table 3 are considered to be proxy species for all entrained species. Therefore, the PM estimates for these species were used to calculate an average PM value. The average loss rate was 13% using ETM^{Avg} and 28% using ETM^{Max}.

The next step in HPF analysis is determination of the habitat area at risk. All the entrained species were assumed to use Elkhorn Slough as their primary habitat. From geographic information system (GIS) mapping it was determined that there were 3,000 acres of habitat that were subject to inundation and therefore could support organisms subject to entrainment. Hence, the estimate of HPF due to entrainment ranged from 3,000 acres × 13% = 390 acres to 3,000 acres x 28% = 840 acres. The logic of the HPF approach is that if 390–840 acres of additional functional wetland habitat were added to the Elkhorn Slough, all the impacts due to entrainment would be compensated. Possible restoration scenarios were examined using a management plan supplied by the Elkhorn Slough Foundation. An example map is shown in Figure 4.

In addition, the plan presented estimates for land purchase and restoration. At the time of the determination (2000), land costs were between $4,000 and $8,000 per acre. In addition, restoration costs were estimated at between $4,000 and $10,000 per acre. Hence the range of reasonable costs to purchase and restore 390 acres of wetland was $3.1 million to $7 million, and to purchase and restore 840 acres, $6.7 million to $15.1 million. The RWQCB and the Energy Commission therefore decided on $7 million, which was paid into a holding account by Duke Energy and later leveraged into more than $21 million. These funds are administered by the RWQCB through a panel of advisors for projects undertaken by the Elkhorn Slough Foundation.

HRC Scaling. To illustrate the calculations involved in an HRC analysis, Appendix E presents a hypothetical example using the loss data in Table 3. As discussed above, the HRC approach is much more data intensive than an HPF analysis, and the required data can be difficult to obtain. For this example, we relied on data in Allen (1982), while recognizing that they may not be directly transferable to the Moss Landing case. In addition, we simplified the analysis by using only point estimates for the variables involved. In practice, data uncertainties should be accounted for by developing confidence intervals or a range of estimates based on multiple data sources, or by conducting a Monte Carlo analysis or some other type of formal uncertainty analysis.

The calculations presented in Appendix E are as follows. First, we expressed the entrainment loss of gobies in Table 3 as a wet weight in grams for consistency with the productivity data in Allen (1982). This involved multiplying the annual loss of 437,000,000 gobies by the average wet fish weight across all captured gobies of 0.28 grams from Allen (1982) for the duration of sampling. This resulted in an estimate of 122,360,000 grams wet weight lost per year. This was converted to a dry weight by multiplying the wet weight by 0.2, the conversion rate given in Waters (1977), resulting in an estimate of 24,472,000 grams dry weight lost per year. Discounting this annual dry weight loss over 30 years using a 3% discount rate yields an estimate of 479,662,001 present value dry weight grams of lost gobies. The use of 30 years was based on the assumed operating life of the new units.[2]

Next, we used Allen's (1982) data to estimate the expected increased production of gobies resulting from littoral zone restoration. As noted above, we simplified this calculation by using the sum of the production estimates only for the reported goby species; in practice, this calculation would be done for each species with quantified losses using species-specific production estimates. Allen's (1982) data indicate an average rate of goby production of 0.2026 grams of dry weight per m^2 of littoral habitat per year, or 820 grams dry weight per acre per year. Adjusting this value by a sampling efficiency of 33% (assumed for the purposes of this example) to account for fish produced but not captured by the sampling gear, results in an estimated 2,485 grams dry weight of gobies produced per acre per year. The present value equivalent of this annual production estimate using a 3% discount rate, assuming that restoration benefits will be realized immediately and in perpetuity, is 82,820 present value grams dry weight of gobies production per acre of restored littoral habitat.

Finally, the acreage to be restored was calculated by dividing the present value dry weight loss of gobies over 30 years (479,662,001) by the present value dry weight gain of gobies per acre of restored littoral habitat (82,820), resulting in an estimate of 5,792 acres of littoral zone restoration required to offset the annual entrainment loss of gobies over the next 30 years.

3.5.3 Comparison and Applications of the HRC and HPF Methods

The major differences between the HRC and HPF methods concern data needs and modeling complexity. The HRC method requires information on rates of growth, mortality, and reproduction of the species lost to express losses of different age and size classes in terms of a single lifestage and to calculate metrics such as production foregone. In contrast, the HPF method uses PM as an estimator; PM can be calculated without these data (see Section 3.1.6.2 for a description of the PM calculation). To express losses in terms of the fraction of organisms in the surrounding waterbody that are lost, both methods require both intake and waterbody sampling data.

However, unlike the HPF method, an HRC analysis addresses losses and gains through time (see Appendix E), and therefore requires information on rates of production or recruitment associated with the restored habitat. This information is not needed for the HPF method, which considers

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[2] Energy Commission staff normally assume the life span of power plants in California to be 30 years.

the average loss in terms of the existing habitat area that is thought to produce the organisms lost. The implicit assumption of the HPF method is that habitat created will produce the equivalent of the organisms lost for as long as the impact. By contrast, the HRC involves direct calculation of species-specific expected increases in production through time resulting from particular restoration actions rather than inference based on the presumed habitat area of the populations at risk.

HRC and HPF results can provide useful information even if habitat restoration is not the most practical or effective restoration option. Even if habitat restoration is not actually implemented, estimates of the scale and cost of restoration provide an ecological basis for quantifying and monetizing losses of wild fish and a context for evaluating the cost-effectiveness of various technological alternatives for minimizing or avoiding losses relative to the cost of increasing natural production to offset losses. This application of the HRC was used in the development of the permit for the Brayton Point facility in Massachusetts (http://www.epa.gov/NE/braytonpoint/index.html).

3.6 Data Availability, Data Issues, and Studies Needed

3.6.1 Data Availability and Data Gaps

3.6.1.1 Life History Data

Life history data such as age/size-specific survival and growth rates are needed for HRC scaling, as discussed above. Such data are generally taken from a review of the scientific literature, databases such as FishBase, an online database of fish life history information, or fish sampling programs by local agencies or universities. The assumption is made that these values represent parameter values for the year and location of the impingement and entrainment study. However, this is unlikely if the studies vary substantially in time or ecological setting, which is often the case. If demographic rates from the literature or field surveys are limited to single observations, it is assumed that rates are constant or represent the mean. In the absence of local empirical data, analyses are constrained by these assumptions.

In addition to the scientific literature, the best sources of life history data for California species are university research studies and agency surveys, including information compiled by Dr. Gregor Cailliet of Moss Landing Marine Laboratories and Dr. Larry Allen of California State University, Northridge. A volume by these researchers on the ecology of California marine fishes is forthcoming.

3.6.1.2 Rates of Secondary Production

Unfortunately, relatively few field studies provide estimates of rates of fish and shellfish production, particularly in California. We reviewed estimates that are available from studies in coastal habitats throughout the United States, and converted all estimates to kilograms of wet weight per hectare per year (kg ww ha^{-1} yr^{-1}). In tidal marsh studies, annual productivity of fish and shrimp in tidal marshes ranged from 540 to 960 kg ww ha^{-1} yr^{-1} for shrimp, from 407 to 800 kg ww ha^{-1} yr^{-1} for mummichog (*Fundulus heteroclitus*), and from 1,105 to 2,425 kg ww

ha^{-1} yr^{-1} for total fish (Strange et al. 2002). Other summaries are provided in Minello et al. (2003) and Cicchetti (1998). Results of an extensive field study provided productivity estimates for several fish species in the littoral zone of tidal marshes in Newport Bay, California (Allen 1982). Production estimates are also available from a study of fishes on an artificial reef in southern California (DeMartini et al. 1994). These data are summarized in Table 4.

Table 4. Estimates from the published literature of rates of secondary production in coastal habitats (in kilograms wet weight per hectare per year, kg ww ha^{-1} yr^{-1})

Habitat	Species	Production per year (kg ww ha^{-1} yr^{-1})	Source
Tidal marsh creeks	Spot (*Leiostomus xanthurus*)	12.5–375	Currin et al. (1984), Weinstein and Walters (1981)[a]
	Mummichog (*Fundulus heteroclitus*)	407–800	Meredith and Lotrich (1979), Valiela et al. (1977)
	Grass shrimp (*Palaemonetes pugio*)	540–960	Kneib (1997), Sikora (1977), Welsh (1975)
Tidal marsh	Blue crab (*Callinectes sapidus*)	360	Cicchetti (1998)
	Atlantic croaker (*Micropogan undulatus*)	1,090	Day et al. (1973)
Littoral zone of tidal marsh	Average of fish assemblage dominated by topsmelt (*Atherinops affinis*)	468	Allen (1982)
Impounded tidal marsh	White shrimp (*Litopenaeus setiferus*)	22	Herke et al. (1992)
	Pink shrimp (*Farfantepenaeus aztecus*)	24	Herke et al. (1992)
	Atlantic croaker	32	Herke et al. (1992)
	Gulf menhaden	45	Herke et al. (1992)
	Blue crab	78	Herke et al. (1992)
Estuaries	Gulf menhaden (*Brevoortia patronus*)	650	Deegan and Thompson (1985)
	Atlantic croaker	1,150	Deegan and Thompson (1985)
Artificial reef	Total production for 11 species	650	Ambrose (1994)

a. Data was given as production per day and extrapolated over an estimated five-month productive period, following Cicchetti (1998).

3.6.1.3 Benefits Analysis

The majority of impingement and entrainment losses are of early life stages and forage species with no direct use value. Unfortunately, there is little empirical information on potential nonuse values of such species. Further study of the nonuse values the public holds for these resources is essential to capture the total value of losses and all the benefits of reducing those losses. An understanding of values provides an important context for evaluating restoration costs (e.g., U.S. Fish and Wildlife Service and Stratus Consulting 2000). Note that although this information provides a perspective on the potential magnitude of secondary productivity in coastal habitats, accurate scaling requires local, species- and habitat-specific estimates such as those in Allen (1982).

3.6.2 Sources of Error and Uncertainty Analysis

3.6.2.1 Estimates of Impingement and Entrainment

There are a number of limitations of impingement and entrainment monitoring programs that can lead to substantial uncertainties and biases in resulting impingement and entrainment estimates. *Uncertainty* refers to random errors that lead to imprecision in an estimate, whereas *bias* refers to systematic errors that affect its accuracy (Finkel 1990; Morgan and Henrion 1990).

Estimates that are biased low may result from monitoring methods that fail to capture all species and life stages. In addition, most studies consider only a subset of "representative important species" or "target species," primarily fish. Macroinvertebrate species (e.g., mussels, crabs, shrimp) are seldom counted.

Another problem is that studies are generally conducted only at the time of the initial permit application. Monitoring is also usually limited to one or two years, which is insufficient to capture the high degree of natural variability common to coastal environments. In addition, monitoring is seldom conducted before and after facility construction or operational and technology changes. Studies of such limited duration can miss high magnitude impingement and entrainment events associated with peak intake flows or seasonal aggregations of organisms. Moreover, it is difficult to adequately sample distributions of organisms that are spatially disaggregated or differ between day and night, as is often the case for impinged and entrained organisms, particularly in marine environments.

Collection efficiency is also an important consideration when evaluating impingement and entrainment data. For example, in some cases the cooling water pump may not be operating continuously during impingement sampling (e.g., Tenera 2000a). Taxonomic identification, particularly of the early life stages that make up most of entrainment losses, is also difficult. Variations in intake flow and changes in species distributions due to ocean currents, waves, tides, and other environmental factors are also common.

Although many sampling errors are unavoidable, variance in impingement and entrainment estimates is seldom accounted for using confidence intervals and other statistical methods for characterizing uncertainty. In addition to these measures, uncertainty analysis should also present major assumptions, biases, and uncertainties in impingement and entrainment analyses, and sensitivity analysis should be performed on the parameters that are most uncertain. Formal methods for addressing uncertainty, including probabilistic methods such as Monte Carlo analysis, are discussed in Morgan and Henrion (1990) and Finkel (1990).

3.6.2.2 Life History Data

Aquatic organisms can be difficult to sample effectively, and as a result there is a general lack of information on life history characteristics such as fecundity and growth and survival rates for most of the life stages and species that are impinged and entrained. These data are necessary for expressing losses in terms of a common life stage or as a fraction of the population in the source water body (Section 3.1.6). Such data are also necessary for quantifying restoration gains relative to impingement and entrainment losses (Section 3.4). To the extent possible, the uncertainty in life history parameter values should be characterized, if only qualitatively, and the parameters that are most uncertain should be identified (Finkel 1990; Morgan and Henrion 1990).

3.6.2.3 Secondary Productivity

Uncertainty in estimates of the scale of restoration is usually addressed by: (1) incorporating uncertainty into measures of losses and gains and (2) incorporating uncertainty into the discount rate (NOAA 1999b). Uncertainty can also be addressed by increasing the estimated scale of restoration required to replace the loss (Thayer 1992). In addition, restoration monitoring and "adaptive management" of restoration actions are essential for addressing uncertainty about restoration effectiveness (Walters 1986).

3.6.3 Other Data Issues

Most early restoration scaling was based on habitat area, assuming that if structure was restored, function would follow (Peterson and Lipcius 2003). However, with increased monitoring of restoration projects, it has become apparent that this is not always the case; indeed restoration of function often lags behind restoration of structure (Simenstad and Thom 1996; Strange et al. 2002). Furthermore, there may not be a simple linear relationship between a structural measure, such as stem density, and productivity, particularly secondary productivity (NOAA 1997). As a result, there is a trend toward defining restoration goals in terms of function, based on direct measures of productivity, rather than in terms of structural measures such as habitat area (Peterson and Lipcius 2003).

Although the general intent of restoration is to increase production, it is important to note that there are circumstances under which increased productivity can actually be harmful (Peterson and Lipcius 2003). For example, excess aquatic primary productivity resulting from nutrient enrichment can lead to anoxia and interfere with energy transfer to higher trophic levels, leading to decreased production of fish and shellfish.

The use of secondary productivity as a scaling metric assumes that the ecosystem services provided are the same, regardless of the size class in which production occurs, which is not necessarily true (Peterson and Lipcius 2003). For example, small size classes are often valuable as prey for larger organisms, whereas large size classes are important for reproduction. In the case of impingement and entrainment, which primarily affects organisms less than one year of age, enhanced production of adults would fail to restore the ecosystem services provided by new recruits such as food for higher trophic levels.

In addition, production rates may vary among different age and size classes. Thus, population size alone may not adequately represent production lost or gained. Use of a demographic population model may help overcome the limitations of using population size as a scaling metric (e.g., French McCay et al. 2003). By considering age and size structure, such a model can account for differences in production among different age groups within a population.

As with secondary production, the data required to parameterize a population model can be difficult to obtain. Such data include age- and size-specific rates of growth, reproduction, and survival. Although reproduction and mortality schedules and information on the factors limiting recruitment and population growth are sometimes available for exploited species, this is seldom the case for the majority of fish species that are not fishery targets. Even for exploited species, it is extremely difficult to develop accurate age-specific estimates of growth, reproduction, and mortality.

It is important to consider potential spatial and temporal variability in fish production. Rates of production at a given population size may also vary from site to site depending on landscape context (NOAA 1997; Minello and Rozas 2002; Peterson and Lipcius 2003). Minello and Rozas (2002) note that the complex distribution patterns of penaeid shrimps, blue crabs, and other nekton in coastal salt marshes at various spatial scales make it difficult to estimate population size. For example, they found higher densities at the marsh edge.

It can be difficult to determine if organisms are actually being produced in the restored habitat or are simply moving into the habitat from other areas. For example, it is difficult to determine if artificial reefs attract or produce fish (Ambrose and Swarbrick 1989; Dixon and Schroeter 1998). Thus, many years of data are often required at both natural and restored sites to determine the relationship between habitat and rates of production.

3.6.4 Studies Needed

One of the most critical needs is to conduct more comprehensive studies of species life histories and rates of recruitment, population growth, and productivity in both natural and restored habitats. Currently, most of the data available are CPUE data from agency surveys that occur irregularly, if at all. Although these data give an indication of relative abundance, CPUE data alone do not provide information on species densities, population growth, or productivity.

There is also a lack of information on growth and survival rates for most of the life stages and species that are impinged and entrained. As a result, much of the information needed to quantify restoration gains relative to impingement and entrainment losses is lacking. Even if literature values are available, transferring them to different species, environmental settings, or time periods can produce uncertainties that are difficult to quantify.

Future studies should focus on developing a mechanistic understanding of the relationships between particular habitat types and increased productivity of particular species and life stages. It is also important to compare production in restored and degraded habitats.

In addition, a standard impingement and entrainment monitoring protocol and standard metrics for quantifying losses should be developed. These standard techniques should be used to conduct monitoring before and after facility modifications or operational changes, and to evaluate potential changes in relative impacts over time as a result of both natural and facility-related impacts.

Finally, more information is needed on public values for impinged and entrained species—particularly nonuse values (Allen et al. 2004b). Such information is necessary to compare total benefits to costs.

3.6.5 Restoration Monitoring

One of the best ways to obtain the data discussed in the previous section is to conduct ongoing monitoring of restoration sites. For example, the restoration project by the Salem facility (PSE&G 1999) has included monitoring of rates of fish production, providing data essential for restoration scaling and helping to fill significant gaps in the scientific literature (e.g., Able and Hagan 2003; Teo and Able 2003). Such information also helps monitor project performance and adjust restoration activities as needed to ensure that restoration goals are met.

4. Conclusions and Recommendations

4.1 Conclusions

Several general conclusions result from project outcomes. These are outlined below according to project objectives.

4.1.1 California Impingement and Entrainment

Our review of impingement and entrainment studies indicates that hundreds of species are affected in California, and yet current impacts are poorly known for most facilities because most existing studies are decades old. Moreover, the majority of species impinged and entrained are forage species whose life histories are largely unknown. Although public values for recreational and commercial fishery species are well known, the ecological value of forage species should be given more consideration in impingement and entrainment reviews. Economic studies of public values for the organisms impinged and entrained will provide a better context for evaluating costs of actions to minimize these impacts.

4.1.2 Restoration Opportunities

Study results indicate that many different kinds of restoration actions, including both habitat and nonhabitat-based alternatives, have the potential to benefit impinged and entrained species. However, additional study is needed to evaluate the ecological value of habitat versus nonhabitat-based alternatives, such as the production of wild species in natural habitats compared to artificial propagation in hatcheries (Strange et al. 2004). There is also a need to identify and prioritize sites for habitat restoration on a regional basis.

4.1.3 Scaling Methods

As our scaling example illustrates, different scaling methods can produce different (but often equally plausible) results, depending on the assumptions and data used. Because many of the current data uncertainties will be difficult to overcome without new field studies, it will be important to develop ranges of scaling estimates using multiple methods.

4.1.4 Data Availability, Data Issues, and Studies Needed

Although updated 316(b) studies including restoration evaluations have been conducted recently at the Diablo Canyon, Moss Landing, and Morro Bay facilities, many more facilities in California require updated studies. Studies of most coastal power plants were conducted decades ago; environmental conditions may have changed substantially at these sites in the interim. In addition, most early studies included limited sampling using study designs and sampling methods that have since been greatly improved. Moreover, few of these early studies considered restoration alternatives to technology implementation or conducted cost-effectiveness analyses. At plants where co-location of desalination facilities is proposed, updated studies are even more important.

4.2 Guidelines for Developing and Evaluating Restoration Proposals

Project results suggest some general guidelines for developing and evaluating restoration proposals:

- **Case-by-Case Review:** Local differences in species mix, environmental setting, and plant characteristics should be considered by means of site-specific reviews of restoration proposals. If data gaps require use of data from other sites, the additional uncertainty that this introduces should be considered explicitly.

- **Cooperative Planning and Analysis:** Given the many data gaps and data uncertainties identified in this report, it is important that permitting agencies, facility operators, and other stakeholders cooperate at the outset in the development of restoration proposals; cooperative planning and analysis will help ensure consensus on restoration goals, the data and methods to use to compare organism losses and gains, and criteria for evaluating restoration success.

- **Define Restoration Goals Explicitly:** It will be important to reach consensus on restoration goals in terms of equivalency and potential tradeoffs that may be required if some goals are not achievable or cost-effective.

- **Use Multiple Scaling Methods:** At present, the best approach to restoration scaling is to use multiple methods. Comparing results of different methods will help determine if estimates are consistent, and therefore more likely to be reliable. In cases where scaling methods produce vastly different results, collection of local, species-specific data may be the only reasonable alternative for reducing uncertainty.

- **Develop Confidence Intervals or Ranges of Estimates:** If data are available, confidence intervals should be developed for restoration estimates. As an alternative, results from multiple studies can be used to create a range of estimates (or confidence intervals, if possible) of both the scale and the cost of proposed restoration actions. Use of a range helps account for uncertainty that may otherwise be difficult to quantify.

- **Compare Restoration and Technology Costs:** Restoration costs should be evaluated in the context of the costs for implementing technologies to reduce impingement and entrainment losses to determine the most cost-effective alternatives for minimizing CWIS impacts. This analysis can be part of a more comprehensive analysis of the environmental and economic costs and benefits of alternative strategies for minimizing impacts.

- **Conduct Ongoing Monitoring and Adaptive Management:** Restoration ecologists view all restoration actions as "experiments." Restoration success is hard to predict and can vary over the time scale of the restoration as a result of random environmental events and other factors that cannot be controlled. As a result, restoration projects should be continuously monitored and results should be continually reevaluated in the context of restoration goals. Restoration actions should be adjusted as needed to improve chances of success. Costs of monitoring and adaptive management should be included in all restoration proposals.

4.3 Recommendations

4.3.1 Biological Studies

Project results suggest that a high priority should be placed on conducting updated impingement and entrainment studies using a standard sampling protocol and quantification metrics. At a minimum, losses should be expressed as adult equivalents and as a fraction of the source population. Studies should be conducted first at facilities where colocation of a desalination facility has been proposed.

In addition to impingement and entrainment monitoring, there is a need for local studies of the life history characteristics of the species impinged and entrained, particularly forage species that have high ecological value but are less well studied than species of commercial and recreational importance.

4.3.2 Benefits Analysis

Although the use values associated with species impinged and entrained are relatively well known, there is little information on potential nonuse values. However, the majority of impingement and entrainment losses are of early life stages and forage species with no direct use value. Therefore, it will not be possible to capture the total value of losses, and the benefits of reducing those losses, without further study of the nonuse values the public holds for these resources. An understanding of values provides an important context for evaluating restoration costs (e.g., U.S. Fish and Wildlife Service and Stratus Consulting 2000).

4.3.3 Evaluation of Potential Sites for Restoration

While this study identifies suitable types of habitat restoration for species lost to impingement and entrainment, it will also be important to identify available sites for these activities. Such information could be integrated into a GIS to help in the development of regional restoration priorities.

4.4 Project Benefits to California

The information provided in this report can benefit California regulators, facility operators, environmental stakeholders, and the Energy Commission in several ways. First, our evaluation of impingement and entrainment impacts provides a comprehensive record of the losses that are currently known. This information and identification of the data needed to parameterize assessment models and scaling methods will also help set priorities for future biological studies.

In addition, our review of restoration opportunities provides a framework for identifying restoration actions to benefit particular species. Our analysis of restoration scaling and our cost-effectiveness analysis indicate that such techniques can play an important role in the permit review process. Such analyses can enhance the review process by expanding the range of alternatives to consider for mitigating impingement and entrainment impacts, helping identify the most cost-effective and environmentally beneficial solutions, and providing a perspective on costs of BTA.

Project results can also help inform regional restoration planning and identify new opportunities for minimizing impacts and maximizing restoration benefits, such as mitigation banking (USFWS 2003). If 316(b) restoration actions are coordinated with other regional restoration activities, the benefits will be maximized.

Finally, the restoration guidelines proposed here are also applicable to restoration planning to address environmental impacts at other kinds of facilities in addition to electric power generators, including hydropower facilities and desalination plants. Use of a consistent and systematic planning and review process will greatly improve the ability of regulators and decision makers to develop and prioritize restoration actions.

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Glossary

AFC	Application for Certification
BACI	before-after-control-impact
BCA	benefit-cost analysis
BTA	best technology available
CCA	California Coastal Act
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CPUE	catch per unit effort
CWA	Clean Water Act
CWIS	cooling water intake structure
EAM	equivalent adult model
EPA	U.S. Environmental Protection Agency
ETM	empirical transport model
FH	fecundity hindcasting
GIS	geographic information system
HEA	habitat equivalency analysis
HPF	habitat production foregone
HRC	habitat-based replacement cost
MLPP	Moss Landing Power Plant
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
P:B	production to biomass ratio
PE	proportional entrainment
PIER	Public Interest Energy Research
PM	proportional mortality
RD&D	Research, Development, and Demonstration
REA	resource equivalency analysis
RWQCB	Regional Water Quality Control Board
SAV	submerged aquatic vegetation
SONGS	San Onofre Nuclear Generating Station
TVE	total value equivalency
VEA	value equivalency analysis

Appendix A: Electric generators in California subject to regulation under Section 316(b), including those subject to certification by the Energy Commission

Facility	Phase of 316(b) Rulemaking	Location	Energy Commission Application for Certification (AFC) application or approval	AFC required?	NPDES permit approval date	NPDES permit expiration date
AES Redondo Beach	2	Redondo Beach			6/29/2000	5/10/2005
Alamitos	2	Los Cerritos Channel			6/29/2000	5/10/2005
Contra Costa	2	Lower San Joaquin River			4/27/2001	4/1/2006
Diablo Canyon Nuclear	2	Diablo Canyon			5/11/1990	7/1/1995
El Segundo	2	El Segundo	Application	12/21/2000, est. decision date: 8/04	6/29/2000	5/10/2005
Encina	2	Aqua Hedionda Lagoon			2/9/2000	2/9/2005
Harbor	2	Long Beach Harbor			6/10/2003	6/10/2008
Haynes	2	Alamitos Bay			6/29/2000	5/10/2005
Humboldt Bay	2	Humboldt Bay			4/26/2001	4/26/2006
Hunters Point	2	San Francisco Bay			5/18/1994	5/18/1999
Huntington Beach	2	San Pedro Channel	Approval	Units 3 and 4: 5/10/2001	6/30/2000	6/1/2005
Long Beach	2	Long Beach			5/24/2001	4/10/2006
Mandalay	2	Channel Islands Harbor, Oxnard			4/26/2001	3/10/2006

Facility	Phase of 316(b) Rulemaking	Location	Energy Commission Application for Certification (AFC) application or approval	AFC required?	NPDES permit approval date	NPDES permit expiration date
Morro Bay	2	Morro Bay	Application	10/23/2000, est. approval date 7/04	3/10/1995	3/10/2000
Moss Landing	2	Monterey Bay	Approval	10/5/2000	10/27/2000	10/27/2005
Ormond Beach	2	Oxnard			6/28/2001	5/10/2006
Pittsburg	2	Suisun Bay	Approval	8/17/1999	6/19/2002	5/31/2007
Potrero	2	San Francisco Bay	Application	Unit 7, 5/31/2000, suspended to 11/14/04	5/18/1994	5/18/1999
San Onofre Nuclear	2	San Clemente			8/11/1999	8/11/2004
Scattergood	2	Playa del Rey			6/29/2000	5/10/2005
South Bay	2	San Diego Bay			11/14/1996	11/14/2001
El Segundo	2	Santa Monica Bay			6/29/2000	5/10/2005
Heber Geothermal Company	3	Heber			6/28/2000	6/28/2005

Sources: www.epa.gov/enviro/html/pcs/pcs_query_java.html, www.energy.ca.gov/sitingcases/ALL_PROJECTS.XLS, www.energy.ca.gov/database/POWER_PLANTS.XLS.

Appendix B: Proposed desalination facilities along the California coast (those in bold are proposed for co-location with a power plant)

Operator/location	Type of project	Maximum capacity	Status
Cambria Community Services District	-Municipal/domestic -Public	500,000 gpd/ 560 AF/yr	Planning
Ocean View Plaza/Monterey	-New development -Private	5,000 gpd/ 6 AF/yr	Planning
Carmel Area Wastewater District	-Municipal/domestic -Public	Not known	Not known
City of San Buenaventura	-Municipal/domestic -Public	Not known	Not known
City of Sand City	-Municipal/domestic -Public	27,000 gpd/ 30 AF/yr	Planning
City of Santa Cruz	-Municipal/domestic -Public	2.5 million gpd/ 2800 AF/yr	Planning
East-West Ranch/Cambria	-Municipal/domestic -Private	Not known	Withdrawn
Marina Coast Water District/Fort Ord	-Municipal/domestic -Public	2.68 million gpd/ 3000 AF/yr	Planning
Long Beach	-Research -Public	300,000 gpd/ 335 AF/yr	Design phase
Long Beach	-Municipal/domestic -Public	10 million gpd/ 11,000 AF/yr	Planning
Los Angeles Dept. of Water and Power	-Municipal/domestic -Public	10 million gpd/ 11,000 AF/yr	Planning
Monterey Bay Shores	-New development -Private	20,000 gpd/ 22 AF/yr	Not known
Monterey Peninsula Water Mgmt. District/Sand City	-Municipal/domestic -Public	7.5 million gpd/ 8,400 AF/yr	Planning
Cal-Am/**Moss Landing Power Plant**	-Municipal/domestic	9 million gpd/ 10,000 AF/yr	Planning
Municipal Water District of Orange County/Dana Point	-Municipal/domestic -Public	27 million gpd/ 30,000 AF/yr	Planning
Poseidon Resources/ **Huntington Beach**	-Various -Private	50 million gpd/ 55,000 AF/yr	Draft EIR completed

Operator/location	Type of project	Maximum capacity	Status
San Diego County Water Authority/**San Onofre Nuclear Generating Station**	-Municipal/domestic -Public	TBD	Planning
San Diego County Water Authority/South County	-Municipal/domestic -Public	50 million gpd/ 55,000 AF/yr	Planning
San Diego County Water Authority & Poseidon Resources/Carlsbad	-Municipal/domestic -Public/private	50 million gpd/ 55,000 AF/yr	Planning
U.S. Navy/San Diego	-Municipal/domestic -Government	700,000 gpd/ 780 AF/yr	Not known
West Basin Municipal Water District	-Municipal/domestic -Public	20 million gpd/ 22,000 AF/yr	Planning

Source: California Coastal Commission (2004).

gpd = gallons per day; AF = acre feet

Appendix C: Species subject to impingement and entrainment in California

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
Anchovies	Deepbody anchovy *Anchoa compressa*		X		
	Northern anchovy *Engraulis mordax*		X		
	Slough anchovy *Anchoa delicatissima*		X		
Blennies	Bay blenny *Hypsoblennius gentiles*			X	
	Combtooth blennies Blenniidae			X	
	Mussel blenny *Hypsoblennius jenkinsi*			X	
	Orangethroat pikeblenny *Chaenopsis alepidota alepidota*			X	
	Rockpool blenny *Hypsoblennius gilberti*			X	
	Tube blenny Blenniidae			X	
Cabezon	Cabezon *Scorpaenichthys marmoratus*	X	X		
California halibut	California halibut *Paralichthys californicus*	X	X		
California scorpionfish	California scorpionfish *Scorpaena guttata*	X	X		
	Spotted scorpionfish *Scorpaena plumieri*	X	X		
Chinook salmon	Chinook salmon *Oncorhynchus tshawytscha*				X (FT, ST, FE, SE, FCT)
Commercial sea basses	Giant sea bass *Stereolepis gigas*		X		
Commercial shrimp	Alaskan bay shrimp Pandalidae		X		
	Franciscan bay shrimp *Crangon franciscorum*		X		
	Ghost shrimp *Neotrypaea californiensis*		X		
	Smooth bay shrimp *Crangon stylirostris*		X		

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Black-tailed shrimp *Crangon nigricauda*		X		
Delta smelt	Delta smelt *Hypomesus transpacificus*				X (FT, ST)
Drums, croakers	Black croaker *Cheilotrema saturnum*	X	X		
	California corbina *Menticirrhus undulates*	X	X		
	Queenfish *Seriphus politus*	X	X		
	Spotfin croaker *Roncador stearnsii*	X	X		
	White croaker *Genyonemus lineatus*	X	X		
	White sea bass *Lates calcarifer*	X	X		
	Yellowfin croaker *Umbrina roncador*	X	X		
Dungeness crab	Dungeness crab *Cancer magister*		X		
Flounders	Bigmouth sole *Hippoglossina stomata*	X	X		
	CO sole *Pleuronichthys coenosus*	X	X		
	Curlfin sole *Pleuronichthys decurrens*	X	X		
	Diamond turbot *Pleuronichthys guttulatus*	X	X		
	Dover sole *Microstomus pacificus*	X	X		
	English sole *Parophrys vetulus*	X	X		
	Fantail sole *Xystreurys liolepis*	X	X		
	Hornyhead turbot *Pleuronichthys verticalis*	X	X		
	Longfin sanddab *Citharichthys xanthostigma*	X	X		
	Pacific sand sole *Psettichthys melanostictus*	X	X		
	Pacific sanddab *Citharichthys sordidus*	X	X		

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Petrale sole *Eopsetta jordani*	X	X		
	Rock sole *Lepidopsetta bilineata*	X	X		
	Slender sole *Lyopsetta exilis*	X	X		
	Speckled sanddab *Citharichthys stigmaeus*	X	X		
	Spotted turbot *Pleuronichthys ritteri*	X	X		
	Starry flounder *Platichthys stellatus*	X	X		
Forage shrimp	Anemone shrimp Decapoda (order)			X	
	Blue mud shrimp *Upogebia pugettensis*			X	
	Broken back shrimp *Hippolyte californica*			X	
	California green shrimp *Hippolyte californiensis*			X	
	Dock shrimp *Pandalus danae*			X	
	Mysids Mysidacea (order)			X	
	Opossum shrimp *Archaeomysis grebnitzkii*			X	
	Oriental shrimp *Palaemon macrodactylus*			X	
	Pistol shrimp *Crangon californiensis*			X	
	Sidestriped shrimp *Pandalopsis dispar*			X	
	Skeleton shrimp *Caprella* sp.			X	
	Stout bodied shrimp *Heptacarpus brevirostris*			X	
	Striped shrimp Decapoda (order)			X	
	Tidepool shrimp *Heptacarpus sitchensis*			X	
	Twistclaw pistol shrimp *Alpheus clamator*			X	

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
Gobies	Arrow goby *Clevelandia ios*			X	
	Bay goby *Lepidogobius lepidus*			X	
	Blackeyed goby *Rhinogobiops nicholsii*			X	
	Blind goby *Typhlogobius californiensis*			X	
	Chameleon goby *Tridentiger trigonocephalus*			X	
	Cheekspot goby *Ilypnus gilberti*			X	
	Long jaw mudsucker *Gillichthys mirabilis*			X	
	Shadow goby *Quietula y-cauda*			X	
	Yellowfin goby *Acanthogobius flavimanus*			X	
Herrings	Middling thread herring *Opisthonema medirastre*			X	
	Pacific herring *Clupea pallasii*			X	
	Pacific sardine *Sardinops sagax*			X	
	Round herring *Etrumeus teres*			X	
	Threadfin shad *Dorosoma petenense*			X	
Longfin smelt	Longfin smelt *Spirinchus thaleichthys*				X (SOC)
Other commercial	Basketweave cusk-eel *Ophidion scrippsae*		X		
	California moray *Gymnothorax mordax*		X		
	Catalina conger *Gnathophis cinctus*		X		
	Leopard shark *Triakis semifasciata*		X		
	Monkeyface prickleback *Cebidichthys violaceus*		X		
	Moray eel *Muraenidae*		X		

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Pacific hagfish *Eptatretus stoutii*		X		
	Pacific hake *Merluccius productus*		X		
	Pricklebreast poacher *Stellerina xyosterna*		X		
	Rock prickleback *Xiphister mucosus*		X		
	Spotted cusk-eel *Chilara taylori*		X		
	Yellow snake-eel *Ophichthus zophochir*		X		
Other forage	Barcheek pipefish *Syngnathus exilis*			X	
	Bay pipefish *Syngnathus leptorhynchus*			X	
	Bigscale goatfish *Pseudupeneus grandisquamis*			X	
	Black bullhead *Ameiurus melas*			X	
	Blacksmith *Chromis punctipinnis*			X	
	Blue lanternfish *Tarletonbeania crenularis*			X	
	Broadfin lampfish *Nannobrachium ritteri*			X	
	Bullseye puffer *Sphoeroides annulatus*			X	
	California clingfish *Gobiesox rhessodon*			X	
	California flyingfish *Cheilopogon pinnatibarbatus californicus*			X	
	California killifish *Fundulus parvipinnis*			X	
	California lizardfish *Synodus lucioceps*			X	
	California needlefish *Strongylura exilis*			X	
	California tonguefish *Symphurus atricaudus*			X	
	Combfish *Zaniolepis* sp.			X	

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Cortez angelfish *Pomacanthus zonipectus*			X	
	Crevice kelpfish *Gibbonsia montereyensis*			X	
	Finescale triggerfish *Balistes polylepis*			X	
	Flathead mullet *Mugil cephalus*			X	
	Fringehead Blennioidei (suborder)			X	
	Garibaldi *Hypsypops rubicundus*			X	
	Giant kelpfish *Heterostichus rostratus*			X	
	Hatchet fish *Gasteropelecidae*			X	
	High cockscomb *Anoplarchus purpurescens*			X	
	Island kelpfish *Alloclinus holderi*			X	
	Kelp gunnel *Apodichthys sanctaerosae*			X	
	Kelp pipefish *Syngnathus californiensis*			X	
	Kelpfish *Chironemus marmoratus*			X	
	Lampfish *Myctophidae*			X	
	Lanternfish *Diaphus splendidus*			X	
	Longfin lanternfish *Diogenichthys atlanticus*			X	
	Longspine combfish *Zaniolepis latipinnis*			X	
	Medusafish *Icichthys lockingtoni*			X	
	Mexican lampfish *Triphoturus mexicanus*			X	
	Northern clingfish *Gobiesox maeandricus*			X	
	Northern lampfish *Stenobrachius leucopsarus*			X	

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Northern spearnose poacher *Agonopsis vulsa*			X	
	Ocean sunfish *Mola mola*			X	
	Ocean whitefish *Caulolatilus princes*			X	
	Onespot fringehead *Neoclinus uninotatus*			X	
	Pacific butterfish *Peprilus simillimus*			X	
	Pacific cornetfish *Fistularia corneta*			X	
	Pacific cutlassfish *Trichiurus lepturus*			X	
	Pacific lamprey *Lampetra tridentate*			X	
	Pacific sand lance *Ammodytes hexapterus*			X	
	Penpoint gunnel *Apodichthys flavidus*			X	
	Pipefish species *Syngnathidae*			X	
	Plainfin midshipman *Porichthys notatus*			X	
	Pygmy poacher *Odontopyxis trispinosa*			X	
	Ratfish Chimaeroidei (suborder)			X	
	Red brotula *Brosmophycis marginata*			X	
	Reef finspot *Paraclinus integripinnis*			X	
	Ribbonfish *Trichiuridae*			X	
	Rockweed gunnel *Apodichthys fucorum*			X	
	Ronquil *Bathymasteridae*			X	
	Saddleback gunnel *Pholis ornate*			X	
	Salema *Xenistius californiensis*			X	

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Sarcastic fringehead *Neoclinus blanchardi*			X	
	Sargo *Anisotremus davidsonii*			X	
	Scarlet kelpfish *Gibbonsia montereyensis*			X	
	Sea porcupine Tetraodontoidei (suborder)			X	
	Sharksucker *Echeneis naucrates*			X	
	Shovelnose guitarfish *Rhinobatos productus*			X	
	Slimy snailfish *Liparis mucosus*			X	
	Smalleye squaretail *Tetragonurus cuvieri*			X	
	Snubnose pipefish *Cosmocampus arctus arctus*			X	
	Southern poacher *Agonidae*			X	
	Southern spearnose poacher *Agonopsis sterletus*			X	
	Specklefin midshipman *Porichthys myriaster*			X	
	Spotted kelpfish *Gibbonsia elegans*			X	
	Spotted ratfish *Hydrolagus colliei*			X	
	Squid Cephalopoda (class)			X	
	Striped kelpfish *Gibbonsia metzi*			X	
	Thornback *Platyrhinoidis triseriata*			X	
	Threespine stickleback *Gasterosteus aculeatus aculeatus*			X	
	Tubesnout *Aulorhynchus flavidus*			X	
	Zebra perch *Hermosilla azurea*			X	

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
Other recreational	Angel shark *Squatina californica*	X			
	Bat ray *Myliobatis californica*	X			
	Big skate *Raja binoculata*	X			
	Black skate *Rajidae*	X			
	Broadnose sevengill shark *Notorynchus cepedianus*	X			
	Brown smoothhound *Mustelus henlei*	X			
	California butterfly ray *Gymnura marmorata*	X			
	Chub mackerel *Scomber japonicus*	X			
	Diamond stingray *Dasyatis dipterura*	X			
	Gray smoothhound *Mustelus californicus*	X			
	Halfmoon *Medialuna californiensis*	X			
	Horn shark *Heterodontus francisci*	X			
	Kelp greenling *Hexagrammos decagrammus*	X			
	Mexican scad *Decapterus scombrinus*	X			
	Monterey spanish mackerel *Scomberomorus concolor*	X			
	Opaleye *Girella nigricans*	X			
	Pacific angel shark *Squatina californica*	X			
	Pacific bonito *Sarda chiliensis chiliensis*	X			
	Pacific bumper *Chloroscombrus orqueta*	X			
	Pacific electric ray *Torpedo californica*	X			
	Pacific mackerel *Scomber japonicus*	X			

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Pacific moonfish *Selene peruviana*	X			
	Pacific pompano *Peprilus simillimus*	X			
	Painted greenling *Oxylebius pictus*	X			
	Rock wrasse *Halichoeres semicinctus*	X			
	Round stingray *Urobatis halleri*	X			
	Senorita *Oxyjulis californica*	X			
	Sevengill shark *Notorynchus cepedianus*	X			
	Soupfin shark *Galeorhinus galeus*	X			
	Striped mullet *Mugil cephalus*	X			
	Swellshark *Cephaloscyllium ventriosum*	X			
	Thornback ray *Raja clavata*	X			
	California sheephead *Semicossyphus pulcher*	X			
	Jack mackerel *Trachurus symmetricus*	X			
	Lingcod *Ophiodon elongatus*	X			
	Pacific barracuda *Sphyraena argentea*	X			
	Piked dogfish *Squalus acanthias*	X			
	Spiny dogfish *Squalus acanthias*	X			
Other commercial crabs	Anthonys rock crab Cancridae		X		
	Black clawed crab *Lophopanopeus bellus bellus*		X		
	Brown rock crab *Cancer antennarius*		X		
	Common rock crab Cancridae		X		

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Cryptic kelp crab *Pugettia richii*		X		
	Dwarf crab *Rhithropanopeus harrisii*		X		
	Elbow crab Mimilambridae		X		
	European green crab *Carcinus maenas*		X		
	Graceful kelp crab *Pugettia gracilis*		X		
	Hairy rock crab *Cancer jordani*		X		
	Kelp crab *Pugettia producta*		X		
	Lined shore crab *Pachygrapsus crassipes*		X		
	Lumpy crab *Paraxanthias taylori*		X		
	Majid crab Majidae		X		
	Masking crab *Loxorhynchus crispatus*		X		
	Mole crab Albuneidae		X		
	Moss crab *Loxorhynchus crispatus*		X		
	Mud/Stone crab *Menippe mercenaria*		X		
	Northern kelp crab *Pugettia producta*		X		
	Pacific sand crab *Emerita analoga*		X		
	Pea crab Pinnotheridae		X		
	Pebble crab *Cycloxanthops novemdentatus*		X		
	Porcelain crab Porcellanidae		X		
	Purple shore crab *Hemigrapsus nudus*		X		
	Red crab *Cancer productus*		X		

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Red rock crab *Cancer productus*		X		
	Sharp nosed crab *Scyra acutifrons*		X		
	Shore crab Grapsidae		X		
	Slender crab *Cancer gracilis*		X		
	Slender rock crab Cancridae		X		
	Southern kelp crab Majidae		X		
	Spider crab Majidae		X		
	Striped shore crab *Pachygrapsus crassipes*		X		
	Thickclaw porcelain crab *Pachycheles rudis*		X		
	Xantus swimming crab *Portunus xantusii*		X		
	Yellow crab *Cancer anthonyi*		X		
	Yellow shore crab *Hemigrapsus oregonensis*		X		
Rec sea basses	Barred sand bass *Paralabrax nebulifer*	X			
	Broomtail grouper *Mycteroperca xenarcha*	X			
	Kelp bass *Paralabrax clathratus*	X			
	Spotted sand bass *Paralabrax maculatofasciatus*	X			
Rockfishes	Aurora rockfish *Sebastes aurora*	X	X		
	Black and yellow rockfish *Sebastes chrysomelas*	X	X		
	Black rockfish *Sebastes melanops*	X	X		
	Blue rockfish *Sebastes mystinus*	X	X		
	Bocaccio *Sebastes paucispinis*	X	X		

Species group	**Species/Latin name**	**Recreational**	**Commercial**	**Forage**	**Special status**[a]
	Brown rockfish *Sebastes auriculatus*	X	X		
	Calico rockfish *Sebastes dallii*	X	X		
	Chilipepper *Sebastes goodei*	X	X		
	Copper rockfish *Sebastes caurinus*	X	X		
	Flag rockfish *Sebastes rubrivinctus*	X	X		
	Grass rockfish *Sebastes rastrelliger*	X	X		
	Kelp rockfish *Sebastes atrovirens*	X	X		
	Olive rockfish *Sebastes serranoides*	X	X		
	Shortbelly rockfish *Sebastes jordani*	X	X		
	Treefish *Sebastes serriceps*	X	X		
	Vermilion rockfish *Sebastes miniatus*	X	X		
	Yellowtail rockfish *Sebastes flavidus*	X	X		
Sacramento splittail	Sacramento splittail *Pogonichthys macrolepidotus*				X (FT)
Salmon	Coho salmon *Oncorhynchus kisutch*	X			
Sculpins	Bonehead sculpin *Artedius notospilotus*	X	X		
	Brown Irish lord *Hemilepidotus spinosus*	X	X		
	Buffalo sculpin *Enophrys bison*	X	X		
	Coralline sculpin *Artedius corallinus*	X	X		
	Fluffy sculpin *Oligocottus snyderi*	X	X		
	Manacled sculpin *Synchirus gilli*	X	X		
	Pacific staghorn sculpin *Leptocottus armatus*	X	X		

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Prickly sculpin *Cottus asper*	X	X		
	Rosy sculpin *Oligocottus rubellio*	X	X		
	Roughcheek sculpin *Ruscarius creaseri*	X	X		
	Roughneck sculpin *Chitonotus pugetensis*	X	X		
	Smoothhead sculpin *Artedius lateralis*	X	X		
	Snubnose sculpin *Orthonopias triacis*	X	X		
	Staghorn sculpin *Leptocottus armatus*	X	X		
	Tidepool sculpin *Oligocottus maculosus*	X	X		
	Woolly sculpin *Clinocottus analis*	X	X		
Silversides	California grunion *Leuresthes tenuis*			X	
	Jacksmelt *Atherinopsis californiensis*			X	
	Topsmelt *Atherinops affinis*			X	
Smelts	Night smelt *Spirinchus starksi*	X	X		
	Popeye blacksmelt *Bathylagus ochotensis*	X	X		
	Surf smelt *Hypomesus pretiosus*	X	X		
Steelhead	Steelhead *Oncorhynchus mykiss*				X (FT)
Striped bass	Striped bass *Morone saxatilis*	X			
Surfperches	Barred surfperch *Amphistichus argenteus*	X	X		
	Black surfperch *Embiotoca jacksoni*	X	X		
	Calico surfperch *Amphistichus koelzi*	X	X		
	Dwarf surfperch *Micrometrus minimus*	X	X		

Species group	Species/Latin name	Recreational	Commercial	Forage	Special status[a]
	Island surfperch *Cymatogaster gracilis*	X	X		
	Kelp surfperch Embiotocidae	X	X		
	Pile surfperch *Rhacochilus vacca*	X	X		
	Pink seaperch *Zalembius rosaceus*	X	X		
	Rainbow surfperch *Hypsurus caryi*	X	X		
	Rubberlip surfperch *Rhacochilus toxotes*	X	X		
	Shiner surfperch *Cymatogaster aggregata*	X	X		
	Silver surfperch *Hyperprosopon ellipticum*	X	X		
	Spotfin surfperch *Hyperprosopon anale*	X	X		
	Striped seaperch *Embiotoca lateralis*	X	X		
	Walleye surfperch *Hyperprosopon argenteum*	X	X		
	White surfperch *Phanerodon furcatus*	X	X		

FT = federally listed as threatened.
ST = state listed as threatened.
FE = federally listed as endangered.
SE = state listed as endangered.
FCT = federal candidate for listing as threatened.
SOC = species of concern.
Source: Refer to Appendix D.

Appendix D: California 316(b) studies reviewed

California 316(b) studies reviewed

Facility	Years of data
Contra Costa	1978–1992
Diablo Canyon Nuclear	1985–1998
El Segundo	1990–2001
Encina	1979
Harbor	1979
Haynes	1979–2001
Humboldt Bay	1980
Hunter's Point	1978
Huntington Beach	1979–2001
Mandalay	2001
Morro Bay	2000
Moss Landing	1979–1999
Ormond Beach	1979–2001
Pittsburg	1978–1992
Potrero	1978–2001
AES Redondo Beach	1979–2001
San Onofre Nuclear	1979–2001
Scattergood	1990–2002

Appendix E: Example of HRC calculations using entrainment losses at Moss Landing and rates of fish production in Allen (1982)

		Source of data and calculation notes
Entrainment losses at Moss Landing		
Total gobies lost at Moss Landing per year to entrainment	437,000,000	From Table 3 of this report.
Average wet weight of goby in grams	0.28000	From Allen (1982), Table 2 (1,419 gobies caught with wet weight of 392.3 grams).
Estimated total wet weight in grams	122,360,000	Product of annual entrainment loss and average goby wet weight from Table 2 in Allen (1982).
Dry weight as a share of wet weight	0.2	From Table 1 in Waters (1977).
Estimated annual loss in dry weight grams	24,472,000	Product of annual entrainment loss in wet weight grams and dry weight conversion factor.
PV loss of entrainment in dry weight grams over next 30 years	479,662,001	PV calculation for 30 year operating life — more acres if longer, less if fewer years.

Present value calculation for loss

Year	PV factor – year 1 discounted	Annual grams lost	PV grams lost
1	0.97	24,472,000	23,759,223
2	0.94	24,472,000	23,067,207
3	0.92	24,472,000	22,395,347
4	0.89	24,472,000	21,743,055
5	0.86	24,472,000	21,109,762
6	0.84	24,472,000	20,494,915
7	0.81	24,472,000	19,897,975
8	0.79	24,472,000	19,318,423
9	0.77	24,472,000	18,755,750
10	0.74	24,472,000	18,209,466
11	0.72	24,472,000	17,679,093
12	0.70	24,472,000	17,164,168
13	0.68	24,472,000	16,664,241
14	0.66	24,472,000	16,178,875
15	0.64	24,472,000	15,707,646
16	0.62	24,472,000	15,250,141
17	0.61	24,472,000	14,805,962
18	0.59	24,472,000	14,374,721
19	0.57	24,472,000	13,956,040
20	0.55	24,472,000	13,549,553
21	0.54	24,472,000	13,154,906
22	0.52	24,472,000	12,771,753
23	0.51	24,472,000	12,399,760
24	0.49	24,472,000	12,038,602
25	0.48	24,472,000	11,687,963
26	0.46	24,472,000	11,347,537
27	0.45	24,472,000	11,017,027
28	0.44	24,472,000	10,696,142
29	0.42	24,472,000	10,384,604
30	0.41	24,472,000	10,082,140
	Total	**734,160,000**	**479,662,001**

		Source of data and calculation notes
Increased production from littoral zone restoration		
Estimated goby dry weight production per square meter	0.2026	Sum of reported results for gobies from Table 3 in Allen (1982).
Square meters per acre	4,047	Standard conversion factor for number of square meters per acre.
Estimated production per acre — grams dry weight fish	820	Product of square meters per acre and dry weight production per square meter.
Adjustment for sampling efficiency of seine	0.33	Assumed for purposes of this example.
Production per acre adjusted for sampling efficiency (dry weight grams)	2,485	Production in dry weight grams per acre divided by sampling efficiency.
Discount rate for present value calculations	3.0%	3% is common discount rate assumption.
Present value multiplier for an infinite annual series of returns	33.33	This multiplier is calculated at the given interest rate as $1/r$, where r is the discount rate.
Present value (PV) production per restored littoral zone acre (dry weight grams per year)	82,820	PV production per acre dry weight = PV factor × adjusted dry weight production.
Required scale of restoration work	5,792	Littoral zone acres to be restored = PV dry weight loss over 30 years/PV DW produced.