# Enhancement Strategies for Mitigating Potential Operational Impacts of Cooling Water Intake Structures

Approaches for Enhancing Environmental Resources

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# REPORT SUMMARY


This report describes environmental enhancement or restoration approaches that may be applicable for mitigating impingement and entrainment impacts associated with cooling water intake structures (CWISs).

## Background

Environmental enhancement approaches (e.g., habitat restoration, restoration of fish passage, fish stocking) are often used to restore aquatic habitats or biological resources that have been affected by such activities as hydropower production, water supply system construction and use, mining, road construction, environmental contaminant cleanup, and commercial development. Environmental enhancements have become a common component of National Pollution Discharge Elimination System (NPDES) permitting under the Clean Water Act (CWA) and relicensing of hydroelectric operations by the Federal Energy Regulatory Commission (FERC). Trading of mitigation or restoration credits, historically considered by the U.S. Environmental Protection Agency (USEPA) for addressing air emissions, is also an emerging approach in water quality permitting.

The USEPA is currently developing Federal regulations to address requirements of Section 316(b) of the CWA. Regulations for new electricity generation sources and draft regulations for existing electricity-generating sources both provide for using enhancements as a voluntary approach to mitigate 316(b) impacts. A need was identified for a review of the state-of-the-science of environmental enhancement and trading to help researchers, regulators, and the regulated community assess the role of enhancements and trading within the Section 316(b) regulatory context.

## Objectives

To determine the state-of-science, including underlying objectives, implementation and operational requirements, costs, current use by government and the private sector, and advantages and limitations of environmental restoration measures for potentially mitigating CWIS operational impacts.

## Approach

Environmental enhancement and trading strategies, decision frameworks, and scaling methods were evaluated against a variety of technical, ecological, regulatory, and operational parameters, including technological status, ability to target CWIS impacts, and the current level-of-use and state-of-the-science. A variety of sources were used to collect information for evaluation, including scientific journals; technical publications; conference and workshop proceedings; government, non-governmental organizations (NGO), and private sector publications and websites; and personal communications with technical and regulatory experts. The project team

did not comparatively evaluate the various enhancement and trading approaches or scaling methods, but rather addressed each on its own merits.

## Results

Enhancement approaches fell into two categories: (1) those that directly address fish numbers and (2) those that address habitat. Stocking addresses fish numbers and may mitigate CWIS impacts by replacing fish directly affected by impingement or entrainment. Habitat restoration mitigates impacts by providing more or better quality habitat to support fish reproduction, growth, and survival. Approaches include restoration of fish passage, creation or restoration of wetlands and submerged aquatic vegetation beds, creation of artificial habitats (such as reefs), and the protection of existing habitat. Enhancement approaches are widely used by a variety of government agencies and NGOs to successfully manage, restore, and/or protect fisheries resources in marine and freshwater environments. They have also been used at many power plants to mitigate for CWIS impacts. Trading approaches could include (1) fish-for-fish trading that allows a cooling water user that provides greater CWIS impact reductions than required by its permit to trade those excess reductions to a second cooling water user; and (2) pollutants-for-fish trading that allows a cooling water user to have relaxed CWIS impact limits in its permit in exchange for reducing the load of key pollutants.

A four-step framework was identified to aid in the selection and scaling of restoration projects to mitigate CWIS impacts. Steps in this framework include: (1) setting the baseline, which determines the type and amount of resources that incur impingement and entrainment impacts and for which mitigation is needed; (2) consideration of technological and/or operational alternatives; (3) selecting the restoration approach; and (4) scaling the restoration project. A critical component of this framework is the need for consultation with regulators, natural resource agencies, and appropriate stakeholders to develop the scope and scale of an appropriate project.

## EPRI Perspective

This report provides energy company managers, regulators, and interested parties with an improved understanding of environmental enhancement approaches that can potentially mitigate CWIS operational impacts. The report will assist researchers, regulators, and the regulated community by identifying the current status and strengths and weaknesses of various enhancement and trading approaches and opportunities for applying these approaches to the regulation of CWIS.


## Keywords

Clean Water Act Section 316(b)
Cooling Water Intake Structure
Fisheries
Environmental Protection and Restoration
Water Quality Trading

# CONTENTS

# LIST OF TABLES

# LIST OF TEXT BOXES

# 1
# INTRODUCTION

## 1.1 Project Background

Cooling water intake structures (CWISs) are used extensively by the electric power industry, as well as other industries, to withdraw cooling water from natural water bodies. CWISs are typically designed to reduce or eliminate the intake of debris and fish. However, concern over the potential for impingement and entrainment of aquatic organisms, particularly fish, has led to the search for strategies to mitigate these potential impacts on aquatic ecosystems.

Environmental enhancements, also known as off-site mitigation, voluntary environmental projects, or restoration (the term used by the U.S. Environmental Protection Agency [USEPA] in its regulations dealing with CWISs) are frequently negotiated as a settlement for real or perceived impacts associated with industrial operations requiring environmental permitting or licensing (Schoenbaum and Stewart 2002). These enhancements are volunteered by the applicant in lieu of technological changes in operations or facilities, particularly where the operational or engineering changes are not economical, where the state of the art for technologically mitigating an impact is limited or of uncertain environmental value, or where the mitigation would have obvious ancillary benefits. The enhancements may also be offered in combination with technical changes when the changes by themselves do not reduce impacts to acceptable levels. Environmental enhancements have become a common component of National Pollution Discharge Elimination System (NPDES) permitting under the Clean Water Act (CWA) and as part of Federal Energy Regulatory Commission (FERC) relicensing of hydroelectric operations. They have been instrumental in resolving complicated debates over the impacts on fisheries caused by cooling water intakes.

Although Section 316(b), which deals with CWISs, has been part of the CWA since 1972, the USEPA has not had national regulations for implementing Section 316(b) in place since the regulations were remanded in 1977. In the absence of national regulations or guidelines, state permitting agencies and USEPA regions have developed a variety of strategies for implementing Section 316(b) on a case-by-case basis. One of these strategies involves using environmental enhancements to offset environmental impacts from CWISs. Regulators have repeatedly followed approved the use of environmental enhancements (Schoenbaum and Stewart 2002).

The USEPA is developing federal regulations to implement Section 316(b). Regulations for new generating facilities were finalized on December 18, 2001. Draft regulations for existing electricity-generating sources were proposed on April 9, 2002, and must be finalized by February 16, 2004. The final new facility regulations allow the use of enhancements, and the proposed existing facility regulations embrace enhancements to an even greater extent. However, the new facility regulations are currently being challenged in court, and the existing facility rules are not yet finalized. While USEPA provides for environmental enhancements as part of the Section 316(b) process, the opportunity to use enhancements is not guaranteed until both sets of rules are finalized.

The intent of this report is to characterize environmental enhancements that have been identified as relevant to Section 316(b), identify their technical merits, present methods or approaches to monitor their effectiveness and to identify approaches for selecting the type and amount of enhancement. The information resulting from this effort will serve as a source document on the technical aspects of environmental enhancements. This report also identifies and evaluates the use of trading strategies as a mitigation avenue for addressing CWIS impacts.

## 1.2 Overview of Environmental Impacts of Cooling Water Intake Structure Operations

Biological impacts resulting from the operation of CWISs generally fall into two main categories: impingement or entrainment. Impingement involves the physical capture of aquatic organisms against the CWIS intake screens that are used to prevent large objects from entering and clogging or damaging electric generating equipment such as pumps and condensers (USEPA 1997, 2002a). Entrainment involves passage of smaller organisms through the intake screens and then through the cooling water system. The principal concern for both impingement and entrainment is that they increase mortality of adult, juvenile, and larval fishes and fish eggs, thereby having potentially adverse effects on fish populations (USEPA 2002a, Dixon and Wisniewski 2002).

## 1.3 Environmental Enhancement Strategies Evaluated in this Report

The categories of environmental enhancements evaluated in this report include:

1. Creation, restoration, and banking of wetlands;
2. Planting of submerged aquatic vegetation (SAV);
3. Construction of artificial habitats (e.g., reefs);
4. Restoration of fish passage; and
5. Supplementation of fish stocks through use of hatchery stocking programs.

A considerable amount of existing knowledge and ongoing research is associated with each of these enhancement approaches (e.g., Arnold et al. 2001, Odeh 1999, Teal and Weinstein 2002), and each may be considered as a distinct multidisciplinary scientific discipline or as a branch of fisheries science.

In addition to these five approaches, this report also evaluates the applicability of habitat protection for mitigating CWIS impacts. In this approach, existing habitat and its associated ecological resources would be protected from threats associated with encroachment of human activities (unrelated to CWIS operations), such as commercial and industrial development. Protection could be achieved through a variety of mechanisms, such as direct purchase and management of habitat, and partnering with other entities (such as The Nature Conservancy or U.S. Fish and Wildlife Service [USFWS]) to identify, purchase, and manage habitat.

Other environmental enhancement approaches that may be relevant to mitigating CWIS environmental impacts but that are not addressed in this report include (1) reducing water quality stressors (such as contaminants originating from point and nonpoint sources unrelated to electric power generation) and thereby increasing aquatic habitat quality and availability; (2) working with federal and state natural resource agencies to control or reduce nuisance species (such as the Asian carp); and (3) providing funds to natural resource agencies or NGOs to perform restoration or protection activities that might otherwise not be conducted. In the future, other enhancement approaches may be developed that could be applicable to mitigating CWIS environmental impacts.

Each of these enhancement approaches has been widely used by a variety of federal agencies (e.g., USEPA, USFWS, U.S. Bureau of Reclamation [Reclamation], U.S. Army Corps of Engineers [USACE]), state and local government agencies (such as various departments of fish and game, natural resources, conservation, and parks), and private sector organizations (e.g., Ducks Unlimited, The Nature Conservancy) to create, restore, and protect aquatic habitats or biological resources (e.g., fish stocks) that have been adversely affected by human activities. These activities include hydropower production; creation, use, and maintenance of water supply systems; mining; road construction; environmental contamination and cleanup; and commercial development. Environmental enhancements have also been used to increase the amount of habitat or fish stocks for conservation, commercial, or recreational purposes, rather than in response to a specific activity impact or effect.

For example, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), one of this country's major environmental cleanup regulations, calls for the compensation and restoration of natural resources injured by chemical releases and any associated cleanup. Under CERCLA, natural resource restoration is addressed through the Natural Resource Damage Assessment (NRDA) process (43 CFR 11), which also requires identification of methods to compensate for past natural resource injuries and to restore or replace the resources (including habitats) impacted by environmental contamination. The environmental enhancement approaches evaluated in this report are commonly used in freshwater, estuarine, and marine systems to provide restoration and/or replacement of natural resources under CERCLA, NRDA, and other environmental programs.

***Wetlands Creation, Restoration, and Banking*****.** Wetlands are a rapidly vanishing ecological resource in North America (http://www.epa.gov/OWOW/wetlands/vital/status.html). Wetland creation, restoration, and banking have been extensively used to protect and manage wetland resources and to enhance or increase fish and wildlife habitat. Wetland creation involves the construction of "new" wetlands at locations that previously had little or no natural wetlands present. It also is used to compensate for habitat impacts associated with contaminant releases and subsequent cleanup at hazardous waste sites, and to restore habitat disturbed by mining operations, highway construction, housing developments, and other construction or excavation activities. Wetland restoration involves the rehabilitation of areas where previously supported wetland communities have been destroyed or degraded. Wetland banking refers to the restoration, creation, enhancement, or preservation of wetlands for purposes of providing compensatory mitigation in advance of authorized impacts to similar wetlands at another location (National Research Council 2001).

***Creation of Submerged Aquatic Vegetation Beds***. Submerged (or submersed) aquatic vegetation (SAV) beds play an important role in many freshwater and marine ecosystems. SAV beds provide nursery habitat for juvenile fish and foraging habitat for fish and wildlife, and they are essential habitat for many invertebrate organisms, such as brown shrimp. In some cases, SAV creation or restoration is used to increase recreational fishery opportunities because of the fish-attracting aspects of SAV beds. Creation of SAV beds often involves the planting of native SAV in areas where historic SAV habitat has been destroyed (http://www.vims.edu/bio/sav/sav001).

***Creation of Artificial Habitats***. Artificial habitats (e.g., reefs) are widely used in freshwater (Tugend et al. 2002) and marine locations to create underwater structures that enhance fish reproduction, growth, and survival, and promote increased production of invertebrate biota. Artificial habitats are used to increase spawning and nursery habitat for some fish species, as well as to provide habitat for other aquatic biota. They are often used to enhance recreational fishing and diving opportunities as well. Creation of artificial habitats to produce relatively permanent fish habitat involves the placement of typically man-made materials such as cobble and boulders, engineered structures, or old ships (for example, see www.dnr.state.sc.us/marine/pub/seascience/ artreef.html and http://www.dcnr.state.al.us/mr/ artificial_reefs.htm).

***Restoration of Fish Passage***. In many river systems, dams, dikes, culverts, and water diversions have been widely used to provide flood control, to generate hydropower, to provide stream crossings, to benefit navigations, and to create lakes and reservoirs for water supply purposes. Each type of structure impacts the ability of resident fishes to move between in-stream habitats. The restoration of fish movements has received significant attention throughout North America and elsewhere. Restoration of fish movement includes use of such technologies as fish ladders, lift gates, and the capture and trucking of fishes around riverine obstacles (OTA 1995, Amaral et al. 1998). The restoration of fish passage to seasonal off-channel habitats, such as flooded bottomlands and backwaters, has been identified as a critical component for the recovery of endangered fishes (CREFRP 2002)

***Fish Stocking***. Fish stocking is widely used in the management of recreational and commercial fisheries in both freshwater and marine systems (Kohler and Hubert 1993, USFWS 2002b). Fish stocking is also being used in the recovery of endangered fishes in areas such as the Colorado River Basin (USFWS 2002h). Stocking involves the production of fish in hatcheries for subsequent release into the wild. Many fisheries in the United States are the result of historical stocking, and some are maintained solely through ongoing stocking. Depending on the species and stocking goals, fish can be stocked from within a few weeks or less of hatching all the way to catchable size.

***Habitat Protection.*** Habitat Protection (i.e., the purchase and management of existing natural areas) has been implemented across the United States and throughout the world to preserve existing land and water resources. Habitat protection can be carried out by an individual agency, but often pooling financial resources yields greater returns. For example, the USFWS works with states to acquire, restore, manage, or enhance coastal wetlands through a matching grants program (USFWS 2003).

## 1.4 Trading Strategies Evaluated in this Report

Historically, USEPA has considered trading of air emissions and (more recently) water-borne effluents (Veil 1998). Neither of these practices is directly applicable to CWIS impacts, but they can serve as models for trading under Section 316(b). This report discusses two types of trading approaches that may have relevance to Section 316(b) issues. These approaches are (1) *trading fish for fish* (i.e., allowing one cooling water user to provide CWIS impact reductions to a greater extent than required by its permit and then trading those excess reductions to a second cooling water user), and (2) *trading pollutants for fish* (i.e., allowing a cooling water user to have relaxed CWIS impact conditions in its permit in exchange for reducing the load of key pollutants.) Generally, these trading strategies would be done within the same watershed or stream segment, but could also be used on other ecologically appropriate scales (e.g., a coastal migratory fish species consisting of single stock could be replaced in another estuary).

These trading concepts are closely related to the use of the other types of enhancements described in this report in that all are designed to offset an impact using an external mechanism. In some situations, enhancements or trading will offer a more cost-effective solution than will installation of additional CWIS technologies. While pollutant-for-fish trading is similar to enhancements, there is an important distinction in how the environmental improvement is effected. Enhancements benefit aquatic populations indirectly by improving habitat or directly by adding new hatchery-raised fish to the ecosystem. Alternatively, pollutant-for-fish trading benefits aquatic populations by improving water quality. It is assumed that better water quality will lead to enhanced populations of aquatic organisms.

## 1.5 Identifying the Appropriate Enhancement Approach and Amount

This report evaluates a number of environmental enhancement approaches that may be employed for mitigating impingement and entrainment impacts of CWIS operations. At any particular location, any number of these (or other) enhancement approaches may be potentially applicable. Because of the dissimilar nature of these enhancements, direct comparison of implementation requirements, costs, success criteria, and environmental benefits can be difficult. Once an enhancement approach (or combination of approaches) has been selected, a determination must be made of the amount of enhancement needed to adequately mitigate impingement or entrainment impacts of CWISs. However, the expected outcomes of the different approaches (e.g., increased habitat) are not necessarily directly comparable to the CWIS environmental impacts (e.g., the annual number of fishes impinged), making determination of an enhancement amount difficult.

A variety of approaches are available that may be useful in helping decision makers select a particular enhancement strategy and determine the amount of enhancement (i.e., the scale) that may be needed to mitigate a known level of CWIS environmental impact. Important considerations in the selection and scaling of enhancements include the determination of the appropriate impingement and entrainment impact baseline, applicability and benefits of best technology available alternatives, development of enhancement goals through interaction with regulators, natural resource agencies, and other stakeholders, and the selection of appropriate metrics to link baseline impacts with enhancement goals and scale the size of the enhancement project. With regards to determining how much enhancement (i.e., scaling the enhancement) may be necessary and appropriate, considerable research has been conducted relating environmental enhancements and fish production (e.g., Teal and Weinstein 2002). Metrics that can be used to scale enhancements include fish/shellfish for direct replacement of fish/shellfish losses, production of equivalent adults, replacement levels based on production foregone, equivalent biomass, net present value, replacement based on use of the random utility model, energy transfer and food chain, and use of American Fisheries Society fish replacement values.

## 1.6 Evaluation Approach

### *1.6.1 Evaluation Parameters*

Each of the six environmental enhancement strategies considered in this report was evaluated against a variety of technical, ecological, regulatory, and operational parameters, including the following:

- Technological status and feasibility,
- Enhancement objectives and target ecological/environmental resources,
- Preferred ecological and/or environmental responses,
- Applicability to target CWIS impacts,
- Current level of use,
- Implementation time,
- Implementation costs,
- Operational and maintenance costs,
- Monitoring requirements and success criteria, and
- Technical and regulatory issues.

The evaluation of the enhancement strategies included consideration of their applications in marine, estuarine, and freshwater environments. Information was also considered regarding selection of the location for implementing a strategy and for determining what level of enhancement might be necessary to mitigate for a specific level of CWIS impact (i.e., a known or estimated level of impingement or entrainment impact).

### *1.6.2 Information Sources*

The variety of sources used to collect information for evaluation in this report included:

- Scientific journals,
- Federal and state agency reports,
- Professional society technical publications,
- Conference and technical workshop proceedings and related publications,
- Technical books,
- Government and private sector web sites,
- Non-government organization publications and other informational materials (e.g., fact sheets), and
- Personal communications with technical and regulatory experts.

Complete citations for all information referenced in this report are provided in Chapter 5. Additional technical information, such as web sites and sources for guidance documents, is provided in Appendix A. Appendix B presents an annotated bibliography of the recent literature on ecosystem restoration issues.

# 2
# EVALUATION RESULTS

## 2.1 Wetlands Creation, Restoration, and Banking

Wetlands are a rapidly diminishing ecological resource in North America, and wetland creation, restoration, and banking have been extensively used to protect and manage wetland resources and to enhance or increase fish and wildlife habitat (http://www.epa.gov/OWOW/wetlands/vital/status.html) (National Research Council 2001). Wetland creation involves the construction of wetlands where none existed previously and may require more extensive engineering of hydrology and soils (Mitch and Gosselink 1993).

Wetland creation can also be used to compensate for habitat impacts associated with contaminant releases and subsequent cleanup at hazardous waste sites, and to restore habitat disturbed by mining operations, highway construction, housing developments, and other construction or excavation activities (Schoenbaum and Stewart 2002). Restoration takes what was once a functional marsh that has become degraded, removes the causes of degradation, and restores the marsh to full function. Restoration projects historically have exhibited a greater success than have wetland creation projects (Kruczyiski 1990) and thus have a higher potential than wetland creation for meeting the goals of CWIS impact mitigation. Successful restoration more often yields wetlands that are functionally equivalent to proximal (nearby) natural wetlands (Shisler 1989), or that meet specific restoration goals (Jorgensen and Mitsch 1989, Zedler 1993). Zedler (1993) identified three major functions on which to assess successful restoration/creation: hydrologic control, water quality improvement, and food chain support. The ability of a restored marsh to meet these generic criteria depends largely on attention to detail in the planning stages (Demgen 1988).

Wetlands banking can be defined as the restoration, creation, enhancement, or preservation of wetlands for purposes of providing compensatory mitigation in advance of authorized impacts to similar resources at another site resulting from approved construction activities (USACE 1996, National Research Council 2001).

### *2.1.1 Wetland Creation and Restoration—State of the Science and Current Use*

Creation and restoration of wetlands have been undertaken for over two decades, primarily to meet regulatory requirements (including compensatory mitigation for wetland losses) and to increase fish and wildlife habitats (Kusler and Kentula 1990, National Research Council 2001). The goals of wetland creation and restoration are generally the replacement or restoration of wetland functions within the landscape. Wetland functions can be grouped into three major categories (National Research Council 1995):

1. Hydrologic functions (e.g., short-term surface water storage, long-term surface water storage, maintenance of a high water table);

2. Biogeochemical functions (e.g., transformation and cycling of elements, retention and removal of dissolved substances, accumulation of peat, accumulation of inorganic sediments); and

3. Habitat and food web support functions (e.g., maintenance of characteristic plant communities, maintenance of characteristic energy flow).

The characteristics of wetland functions are becoming better understood (Adamus and Stockwell 1983, Adam 1990, Adamus et al. 1991, Brinson 1993, Zedler 2001). The *National Action Plan to Implement the Hydrogeomorphic Approach to Assessing Wetland Functions* (Department of Defense et al. 1997) was developed by a federal interagency working group to provide regional guidance for assessing the functions of existing wetlands on the basis of influencing hydrology and geomorphology.

Understanding the relationship between wetland characteristics and functions has made possible the successful design of wetlands to provide specific functions (Marble 1992), and the success of wetland creation and restoration projects has greatly increased over early attempts. A large number of wetland restoration projects have demonstrated the potential for successful rehabilitation of degraded or impacted wetland systems (RAE and ERF 1999, Rozas and Minello 2001, Weinstein et al. 2001, Havens et al. 2002, Poulakis et al. 2002, Swamy et al. 2002).

Wetland restoration and creation have frequently been undertaken to provide compensatory mitigation for permitted impacts to wetlands (e.g., under Section 404 of the Clean Water Act [CWA], Section 10 of the River and Harbors Act, the wetland conservation provisions of the Food Security Act, and CERCLA). Compensatory mitigation generally involves replacing wetland functions that have been lost from the landscape with the same type of wetland that was lost and in the same watershed. Evaluations of existing wetland restoration and creation projects have led to an understanding of potential causes of failure and ways to increase the likelihood of success (Kentula et al. 1992, National Research Council 2001, Race and Fonseca 1996, Bohlen et al. 1994, Weinstein et al. 1997, RAE-ERF 1999, Brown and Veneman 2001, Robb 2001, Campbell et al. 2002, James-Pirri et al. 2001).

### *2.1.2 Implementation Approaches*

Wetlands provide numerous functions within the landscape, such as the development and maintenance of characteristic plant communities (which provide habitat for fish and wildlife), surface water storage (which helps maintain fish habitat), and the accumulation of sediments (which maintains water quality) (National Academy of Sciences 1995; Interagency Workgroup on Wetland Restoration undated, Mitsch and Gosselink 1993, also see http://www.epa.gov/

OWOW/wetlands/vital/status.html). Establishment or restoration of these wetland functions is an important component of a successful wetland mitigation project (SWS 2001). The characteristics of wetland communities that are restored or created, including structure, species, and hydrology, should be similar to undisturbed regional wetland types.

Increases in the understanding of wetland functions and evaluation of previous wetland restoration and creation attempts have yielded guidance for the successful establishment of wetlands. It should not be assumed that every degraded site can be reversed. Therefore, a range of targets for restoration (both approaches and sites) should be identified (Lindig-Cisneros et al. 2003). A list of guidelines and other information sources for wetland restoration and creation is provided in Appendix A. Guidelines for performance standards, or success criteria (SWS 2001, USACE 1998, 2001), as well as conservation practice standards (NRCS 1998a,b), have also been developed for wetland creation and restoration.

The goal of wetland restoration generally is to reestablish ecological communities and processes in damaged or lost wetlands. A specific objective must be established to determine the type of wetland restoration site and the specifics of the design of the restoration. As an example, the Public Service Electric & Gas's (PSE&G's) Estuary Enhancement Program is restoring or preserving more than 10,000 acres of salt marsh on Delaware Bay in order to increase production of aquatic organisms to offset losses due to CWIS operational impacts (Weinstein et al. 1997, Mitsch and Gosselink 1993, Public Service Enterprise Group 1999a, Mitch 2000, Weinstein et al. 2001, Vivian-Smith 2001.) However, wetland creation often establishes wetland communities on sites that have not previously supported them. Several wetland functions that frequently are associated with wetland creation and restoration are: (1) surface water storage (which reduces downstream flood peaks through the absorption of storm-water flows); (2) the retention, transformation, and removal of nutrients, sediments, and contaminants (which maintains or improves water quality); and (3) the establishment of wetland plant communities (which provides habitat for invertebrates, fish, and wildlife). Wetland characteristics that are associated with specific functions can be incorporated into the design of restored or created wetlands. Wetland restoration or creation can include various wetland types (e.g., tidal salt marsh, freshwater marsh, forested riparian, or other wetlands) (Kusler and Kentula 1990, National Research Council 2001). Components of wetland restoration and creation projects include establishment of appropriate hydrological conditions, soil preparation (including contouring and amendments), revegetation, and streambank stabilization. For example, Perry et al. (2001) provide a number of recommendations for creating tidal salt marshes.

Site selection is a major factor in the success of wetland creation and restoration projects. Site selection should favor those locations that can sustain an appropriate hydrology with minimum manipulation during both construction and ongoing operation. Former wetland sites to which natural hydrologic regime can be restored are preferable to sites that require extensive and complex engineering. The site selection process should begin on a landscape basis within the watershed or other ecological unit being considered (Mitch and Gosselink 1993). Surrounding land use and the extent of disturbance within the watershed are also important considerations in site selection, as well as potential restrictions on the restoration techniques available (Mitsch and Gosselink 1993, Simenstad, et al. 2000, National Research Council 2001, Vivian-Smith 2001.) Site-specific considerations include appropriate elevation, hydrology, and soils, presence of vegetation, plant propagules, and fauna on the site, and appropriate sediment in suspension in tidal areas (Mitsch and Gosselink 1993, Weinstein et al. 2001, Vivian-Smith 2001, Levin and Talley 2002, Raposa and Roman 2003, Lindig-Cisneros et al. 2003).

For example, Public Service Enterprise Group (1999a,b) has developed a systematic process to identify and secure wetland restoration sites in the Delaware Estuary that exhibit conditions favorable for restoration. The evaluation process was conducted within a decision framework that balanced multiple, diverse factors and prioritized the sites for land acquisition. An inventory of the Delaware Estuary was initially developed through review of aerial photographs to quantify the extent of degraded wetlands potentially available for restoration. Following the initial evaluation, available resource documents were reviewed, and field reconnaissance of potential sites was conducted to identify properties suitable for restoration.

Salt hay farm sites were identified and acquired first. Then, other impoundments and *Phragmites*-dominated sites were considered. These sites were evaluated systematically to achieve the following objectives: (1) maximize restoration reliability, as determined by existing environmental conditions; (2) avoid time delays so that the exacting permit time frames would be satisfied; and (3) maximize ancillary benefits that would accrue to the restoration and adjacent areas.

Baseline evaluation of the Delaware Estuary wetlands consisted of a review of aerial photographs to determine historical land use practices, followed by field visits to prospective sites to obtain information on tide range, salinity, and other site features such as marsh elevation, vegetation characteristics, and tidal creek geomorphology. Acceptable sites were required to have suitable sediment/soil substrate characteristics, including high sediment organic content and close proximity to *Spartina* salt marshes for revegetation and faunal recolonization, and were expected to have appropriate salinity and marsh plain elevation to support the growth of *Spartina* spp. and other desirable, naturally occurring marsh vegetation. On the basis of a review of various environmental, ecological, and socioeconomic factors, sites were ranked according to the likelihood that restoration to a *Spartina*-dominated salt marsh was practicable.

Critical to the proper design and evaluation of a wetland restoration is the use of appropriate reference sites (Kusler and Kentula 1989a,b, Aronson et al. 1996, Hobbs and Norton 1996). During the design phase of wetland creation or restoration, relatively undisturbed wetlands should be selected as reference wetlands within the same region to represent wetland types with similar hydrogeomorphic settings and wetland functions as the proposed wetland. Characteristics of these reference wetlands are used to establish hydrologic, vegetation, soil, or fish population criteria; to develop project plans; and to compare against the created or restored wetland to evaluate project success. As distance between the reference wetland and the restoration wetland increases, similarities will be reduced (Tobler 1970), as will the usefulness of the reference wetland in evaluating restoration success. It is important to keep in mind that no reference wetland can be a perfect match for a restoration site (White and Walker 1997).

Once a wetland site has been identified and acquired, an ecologically appropriate design must be developed. Before design work actually begins, however, a variety of site-specific data must be obtained. These data include topography, hydrology, hydroperiod, morphology, soils, site vegetation, and any other relevant ecological parameters (Mitsch and Gosselink 1993, PSE&G 1999, Vivian-Smith 2001). This information is then used during the design of the restoration. It is important that scientists, engineers, or other technical experts with requisite expertise be involved with the restoration/creation design.

The design of the site should be based on the watershed or regional data, with particular emphasis on the site-specific data. The design must address the restoration objectives previously established and incorporate ecological engineering principles. Ecological engineering is a restoration approach whereby a natural process is initiated by humans and completed by nature (Mitsch and Gosselink 1993, Mitsch 2000, National Research Council 2001, Weinstein et al. 2001).

The initial site work for wetland creation and restoration generally can be completed within the first year, including establishment of required hydrologic conditions, soil preparation, and planting. Soil preparation may require removal of contaminated soils or fill material, or soil supplementation. In severely degraded wetlands, restoration efforts may include replacing existing soils, with subsequently improved soil structure and chemistry, as well as providing soil microorganisms. Stream channel and coastal wetland restorations often require streambank or shoreline stabilization to prevent erosion and to quickly establish riparian vegetation. Methods of soil stabilization include use of natural or artificial fiber rolls or mats in combination with plant materials (FISRWG 1998, Blama et al. 1995).

Wetland creation often requires extensive soil contouring and grading to establish the desired topography. Tidal marsh restorations have used dredged material to raise the substrate elevation in subtidal areas to intertidal levels (Blama et al. 1995, Garbarino et al. 1995, Callaway 2001, Costa-Pierce and Weinstein 2002). Filled geotextile tubes may be used (and may be combined with riprap structures) to provide erosion protection for the dredged material. Elevational heterogeneity increases biodiversity (e.g., creating patterns of high marsh and low marsh wetlands) and can be developed by excavation of selected areas or placement of fill. Sometimes soils are altered by incorporating organic material to decrease bulk density, increase water holding capacity, and increase productivity. Fine-textured sediments may need to be added to coarse substrates, or natural sedimentation may be used to establish desired substrate levels and texture. Where possible, wetland soils are salvaged and used to provide the appropriate substrate texture, chemistry, and microorganisms (Callaway 2001).

Developing the desired hydrological regime is essential to wetland creation or restoration success. Hydrologic modification of the site may require the control of surface water flow entering and exiting the site. This control may be accomplished by the construction of such structures as levees, dams, weirs, or gates and may require pumping or diverting surface water flows. However, such measures generally require continued maintenance and are costly. Natural surface water and groundwater patterns are preferable to those that require continued human intervention. In some locations, the establishment of wetland hydrology by groundwater sources is preferable to the use of surface water flows for the successful establishment of native biotic communities, because of water level fluctuations, poor water quality, altered water chemistry, or high nutrient levels associated with surface water flows. Hydrologic restoration of drained wetlands may only require the filling or blocking of drainage ditches, or the disabling of agricultural drain tiles. These tiles are typically excavated and either broken up or removed, allowing natural groundwater flows to reestablish the frequency and duration of soil saturation necessary for wetland restoration (Admiraal et al. 1997). In some cases, it also may be possible to install valves in existing drain tiles to allow control of water levels.

Restoration or creation of tidal wetlands involves the establishment of natural tidal flows on the site (Weinstein et al. 2001, Zajac and Whitlatch 2001, Bakker et al. 2002, Poulakis et al. 2002, Raposa 2002, Swamy et al. 2002, Raposa and Roman 2003). Restoration may be accomplished by the removal or breaching of existing dikes or levees to restore tidal flow. The establishment of a network of tidal creeks with a high degree of sinuosity (including small, narrow channeled creeks with steep banks) can improve development of a suitable hydrologic regime and habitat value in tidal marsh projects. Such a network can be developed by excavation of channels with small backhoes (Zedler 2001).

In larger-scale projects or where a heavier reliance on ecological engineering occurs, construction of only the higher-order tributaries may be desirable. In these cases, the placement and development of lower-order streams proceeds as a result of natural processes in response to the hydrodynamics of the site (Weinstein et al. 2000a).

Preparation of the wetland restoration or creation site may require the removal of invasive non-native species or control of destructive animals such as geese and muskrats (Perry et al. 2001). The presence of invasive species such as common reed (*Phragmites australis*) or purple loosestrife (*Lythrum salicaria*) may prevent the successful establishment of native communities. Methods used to control invasive species include applications of herbicides (e.g., glyphosate), prescribed burns, biocontrol (e.g., the release of host-specific beetles [*Galerucella* spp.]) to eradicate purple loosestrife), or a combination of these approaches. Aerial spraying of glyphosate, followed by burning, can be effective in removing common reed in large restoration projects. A combination of cutting and submerging has also been used to remove invasive species.

Following removal of invasive species, planting of native wetland and terrestrial vegetation along a hydrologic gradient may be required (Lindig-Cisneros and Zedler 2002). By using a hydrologically open design, a created or natural wetland can develop a diverse assemblage of plant species using self-design (or ecological engineering) (Mitch et al. 1999). A temporary cover crop of a non-competitive annual grass (such as annual rye) can be planted to stabilize soils and reduce erosion potential. In some cases, revegetation of the wetland restoration site from the natural seed bank is possible. Natural revegetation may also be effective if salvaged wetland soils are used, providing the duration of soil storage was minimized or if an adequate natural seed source is available in the vicinity. Native plant communities are often planted or otherwise established in upland buffer areas to reduce adverse influences of adjacent areas of the watershed. Planting can be by direct seeding, or by installing live plugs, bare root seedlings, or cuttings. Planting can be done both manually and by mechanical planters (Sullivan 2001, NRCS 2000). Plants may be salvaged from the wetland restoration site before initiating soil modification or from a wetland site being eliminated. Greenhouse-grown plants may require a period of adjustment to natural conditions, such as sun exposure or soil salinity (if used in salt marsh projects). In addition, the introduction of vegetation and sediment cores from natural wetlands and introduction of poorly dispersing invertebrates may lead to the development of a more natural invertebrate community in a shorter time (Brady et al. 2002).

More than 95% of commercially harvested fish and shellfish in the United States are wetland dependent (Feierabend and Zelazny 1987). The degree of dependence of fish on wetlands depends upon the species and type of wetland habitat. Virtually all freshwater fish species depend on wetlands for part of their life history (Mitsch and Gosselink 1993). Coastal wetlands of the northern Gulf of Mexico, because of their flooding and fragmentation patterns, sustain large populations of penaeid shrimps and blue crabs (Zimmerman et al. 2000); Pacific Northwest anadromous fish, such as salmon, depend on estuarine wetlands, particularly regarding the structural complexity and scale of the estuarine landscape (Simenstad et al. 2000); and shellfish, such as mussels and oysters, benefit from estuarine marsh production of suspended materials (such as phytoplankton) and contribute to the exchange of inorganic nutrients between the benthic zone and water column (Dame et al. 2000).

While salt marshes have been demonstrated to serve as important nurseries for resident and transient fishes (Gunter 1956, Nixon and Oviatt 1973, Daiber 1977, Weinstein 1979, Boesch and Turner 1984, Rozas et al. 1988, Rountree and Able 1992, Ayvazian et al. 1992, Minello and Zimmerman 1992, Baltz et al. 1993, Kneib 1997, Deegan et al. 2000, Beck et al. 2001), there are gaps in the knowledge of the life histories of fish and their use of salt marsh habitats (Rountree and Able 1992, 1993, Kneib 1997). The available data suggest that salt marshes function as sites for reproduction, food, and predator refuge for fishes and other animals and therefore promote growth and survival (Thayer et al. 1978, Boesch and Turner 1984, Kneib 1987, 1997, Deegan et al. 2000, Miller et al. 2003).

Habitat for fish and wildlife has been successfully established in created or restored wetlands (Kusler and Kentula 1990, National Research Council 2001, Rozas and Minello 2001, Weinstein et al. 2001, Muir Hotaling et al. 2002, Poulakis et al. 2002). Restoration can often rapidly establish a wetland community, including invertebrates and soil microorganisms, and subsequently develop habitat for fish spawning, foraging, or refuge. In created tidal marshes, frequently inundated low marsh vegetation can reach biomass levels equivalent to natural marsh in 3 years, although seldom flooded high marsh vegetation may take more than 15 years (Craft et al. 2002). Faunal reestablishment in restored marshes, particularly in coastal wetlands, has been well documented (Mitsch and Gosselink 1993, Zedler et al. 1997, Able et al. 2000, 2001, Lathrop et al. 2000, Tupper and Able 2000, Wainwright et al. 2000, Weinstein et al. 2000b, Levin and Talley 2002, Miller and Able 2002, Roman et al. 2002, Teo and Able 2003). Fish communities often develop in 5 years or less, although at least 10 years and possibly 20 years or more may be required for the development of mature wetland communities similar to natural undisturbed wetlands and development of full habitat function (Simenstad and Thom 1996, Swamy et al. 2002, Craft et al. 1999, Havens et al. 2002, Hampel et al. 2003). Forested wetlands may take considerably longer to restore to maturity (NRCS 2000, Haynes and Moore 1988).

Wetlands also may be designed to improve the quality of surface water runoff from upland areas prone to erosion or containing contaminants, such as runoff from agricultural fields. With proper design, created or restored wetlands that intercept surface water flows can reduce the velocity of surface flows and capture sediments, nutrients, or contaminants by the establishment of vegetation communities, thereby improving downstream water quality.

Developing a wetland creation or restoration project will require coordination with local, regional, state, and federal regulators. State environmental agencies review National Pollutant Discharge Elimination System (NPDES) permit applications for cooling water systems and coastal development permits and would be expected to develop guidelines for compensating fish losses and identifying the type and amount of wetlands that would be created, restored, or protected to provide compensation. Methods and procedures for monitoring of fish populations as well as for monitoring the created or restored wetlands may be specified. In addition to coordination with USEPA and state agencies, involvement of the U.S. Army Corp of Engineers (USACE) may be required if the work site involves existing wetlands, as may likely occur with restoration projects.

### 2.1.3 Wetland Banking—State of the Science and Current Use

Wetland banks are developed by the same methods discussed above for wetland creation and restoration projects. The establishment of a large wetland, as through a wetland bank, may result in greater success than small, individual wetland creation projects. For this reason, compensation requiring relatively small wetland areas may be more efficiently accomplished in combination with other wetland creation or restoration efforts. Following successful project completion and approvals for use by applicable state and federal agencies, areas of the wetland bank become available as "credits." Credits in an existing wetland bank could be purchased to provide the wetland area required for compensation for CWIS impacts. These areas would be subsequently "debited" or removed from future availability. Wetlands banking would allow the rapid fulfillment of compensation requirements for CWIS impacts, since the required wetland area would be constructed and performing desired functions at the time of the impact determination. Wetland banks have been established in many states. Many have been developed by the state departments of transportation to compensate for multiple wetland losses resulting from road construction. Banks also are often used by land developers to fulfill Section 404 permit requirements.

Currently, 30 states have developed guidelines for the establishment and operation of wetland banks (Mehan 2001, VMRC 1998, DOA 2002) that are designed to ensure the long-term success of the wetland and appropriate allocation of credits. In addition, five federal agencies have established policy guidance for wetland banks that includes planning, establishment, criteria for use, long-term management, and monitoring (USEPA et al. 1995). Monitoring and maintenance of the wetland is generally performed by the bank sponsor and is designed and implemented in accordance with the authorizing agencies.

Wetland bank credits are generally determined by one of two measurement frameworks—acreage or habitat units. The specific method is identified in the operational guidelines approved for each bank. Credits may be determined in terms of wetland acres, based upon the number of acres within a particular bank required to provide compensation for a specific wetland impact, and generally interpreted as a mitigation ratio. Wetland bank credits also may be expressed as habitat units (Wilkey et al. 1994, McCrain 1992, Fernandez and Karp 1998), reflecting the habitat value of the wetland being credited, based on Habitat Evaluation Procedures (USDA 1980). Costs per acre for mitigation bank credits range widely (e.g., $2,300 for a wetland bank in Missouri [MLDDA 2000]; $13,000 to $20,000 in Ohio [OLSC 2001]; and $50,000 to $55, 000 in Florida [Szabo and Bleichfeld 1998]).

### *2.1.4 Applicability for Mitigating CWIS Operational Impacts*

The impacts of CWIS that could be addressed by wetland restoration, creation, and banking are the entrainment and impingement losses of eggs, larvae, juvenile, and adult fish. Implementation of wetland restoration and creation projects, or purchase of bank credits, could be directed to benefit the affected fish species, invertebrate food production, and aquatic and terrestrial biota and processes. In some cases, in addition to benefiting target species impacted by CWIS, the wetland project may also benefit other, perhaps less desirable, species (e.g., carp). However, consideration of such species would be included in project goals determined by permitting authorities. The value of a restoration or creation project may be increased if the project is designed to benefit commercially or recreationally valuable species or threatened or endangered species. For example, restoration of a salt marsh in Delaware Bay created conditions favorable to the mummichug (*Fundulus heteroclitus*), which is an important dietary component of the Atlantic croaker (*Micropogonias undulatus*) and striped bass (*Morone saxatilis*) (Teo and Able 2003). The ultimate goals of this enhancement alternative are to increase production, survival, and growth of selected fish species by providing or improving spawning, nursery, and foraging habitat availability or quality. These goals would be realized as increased growth of juveniles and adults, increased reproduction, increased survival of juveniles and adults, and improved condition. The impacts of impingement might be offset by increased growth and survival of juveniles and adults, while larval entrainment might be offset by increased production, survival, and recruitment of larvae. The impacts of egg entrainment might be offset by increased egg production, survival, and hatching success. Implementation of this enhancement alternative would be expected to result in a long-term increase in early adult lifestage of target species. Additional benefits resulting from wetland restoration and creation, that are not directly related to CWIS impacts but have public value, could include increased water quality, increase in habitat for terrestrial or other aquatic species, increase in the food base for fish and wildlife, increased biodiversity, and increases in flood control. Methods to determine the form of wetland restoration or creation or amount required to offset CWIS impacts may include an ecological risk assessment (ERA) framework (EPRI 2001). The ERA framework can be used to assess the risk of adverse ecological impact and compare potential ecological benefits of possible alternatives used to reduce any ecological impacts.

Wetland creations, restorations, or banks would typically be located along the body of water where the CWIS-related impacts to fish occurs, or along its tributaries. However, the location could vary if the compensation goal is directed toward fish populations other than those directly impacted or other wildlife species as determined by the permitting authorities.

The preferred location of the restoration would be close to the area where CWIS operational impacts were being incurred, thereby increasing the likelihood that the restoration would benefit the impacted fish species. The restoration site-selection process should also consider the ecology of the species affected by CWIS operations, or of the target species to be benefited by the restoration. In the case of an estuarine power plant, many of the species involved are coastal migratory species that spawn over large geographic regions within specific ecological zones (e.g., weakfish [*Cynoscion reglis*] spawn in poly-mesohaline regions.) On the other hand, some species (spot [*Leiostomus xanthus*] and Atlantic croaker) spawn offshore, and the juveniles use many of the estuaries (meso to polyhaline regions) along the coast for nursery functions. The location of the wetland would not have to be within the same watershed as the power plant.

As directed by the New Jersey PDES permit for its Salem Generating Station, located on the Delaware Estuary, PSE&G was required to restore a minimum of 10,000 acres of tidal marsh wetlands for fish breeding and nursery areas (Patterson 2001). Under the Estuary Enhancement Program subsequently developed by PSE&G, more than 20,500 acres of land in and around the Delaware Estuary has been restored and/or preserved (Weinstein et al. 1997, 2000a, 2001, RAE-ERF 1999, Able et al. 2000, Tupper and Able 2000, Miller and Able 2002). The 10,000-acre target was derived partially by modeling, which resulted in a lower value, and partially to accommodate uncertainties (Teal and Weinstein 2002). The San Onofre Nuclear Generating Station, located on the southern California Pacific coastline, was required in its coastal development permit to restore 150 acres of tidal marsh (CCC 2001). The restoration site, San Dieguito Lagoon, is located approximately 30 miles south of the station, along the San Dieguito River, which discharges into the Pacific Ocean.

Following a determination that CWIS operation has resulted in entrainment and impingement losses of fish, an environmental enhancement method would be selected to offset those losses. Section 4 of this report presents approaches that may be used to determine the appropriate enhancement method for a particular CWIS impact. The mitigation of impacts through implementation of wetland creation, restoration, or banking would involve an initial determination of the type and amount of wetland area that would be required to compensate for the number of fish eggs, larvae, juveniles, and adults impacted by the CWIS. A number of methods are currently used in determining requirements for mitigation of wetland impacts under various state and federal wetland programs. These methods and others that may be applicable to a determination of wetland type and area for CWIS impact mitigation are discussed in Section 4.4.

### 2.1.5 Cost

Costs associated with implementation of a wetland creation or restoration project may be moderate to high, increasing with wetland area, degree of hydrologic modification required, extent of substrate modification, and amount of excavation or grading. The need for land contouring generally results in higher costs for wetland creation. The extent to which a natural wetland system has been degraded will affect the types and degree of restoration efforts needed to return wetland functions and will affect the costs. Soil replacement or removal of fill material can greatly increase the cost, especially if excavation and disposal of contaminated soils is involved.

The total costs for wetland restoration and creation projects include the costs of development and design, land acquisition, construction/implementation, maintenance, and monitoring. Estimates or summaries of project costs often omit costs of a number of these aspects, such as design costs or monitoring costs. In addition, reported costs for wetland creation and restoration vary widely because of site-specific differences in implementation and contractor costs.

Example cost estimates for a number of tidal marsh restoration projects range across two orders of magnitude:

- Arcata Marsh and Wildlife Sanctuary, Arcata, California (total of 315 acres) developed by city of Arcata: $6,127 per acre (Neander 2002).
- Montezuma Wetlands Project, Solano County California: $10,000 to $30,000 per acre. Costs for monitoring currently at $250,000 per year and projected to increase (Levine 2002).
- Hudson/Raritan Bay, New Jersey (currently 20 acres, 300 acres planned), developed by a group of federal agencies, state, and municipal governments: $100,000 to $250,000 per acre (Sacco 2002).
- San Onofre Nuclear Generating Station, California (total of 150 acres): $573,000 per acre (projected) (Kay 2002).
- Estimated costs for tidal marsh, developed by USEPA, based on 8 replanting/reseeding projects (USEPA 2001a): $10,344 per acre; estimate for freshwater wetlands based on 15 projects: $12,047 to $18,535 per acre.
- Salem Generating Station (Estuary Enhancement Program), Delaware Bay (10,700 acres of active restoration), capital, O&M, and monitoring costs: $9,350 per acre (J. Pantazes pers. comm.)

Janvrin (2002) presented estimates of habitat restoration costs for the Upper Mississippi River system. Information included acres to be restored, estimated costs per acre of restoration, and maintenance costs following restoration. For example, 100,000 acres in need of marsh restoration were reported. Restoration costs were estimated at $4,000 per acre, with operation and maintenance costs estimated at $250 per acre.

### *2.1.6 Monitoring and Maintenance*

Three reasons for monitoring restored wetlands are (1) documenting a restoration program's performance, (2) validating the restoration design criteria, and (3) supporting adaptive management of restored sites (e.g., correcting design or construction mistakes) (STAC 2002). See Section 4.4 for further discussion on adaptive management.

Monitoring typically is required to confirm the satisfactory establishment of hydrology and biotic community goals (e.g., vegetation, fish, and wildlife species diversity and density). For wetlands designed to compensate for CWIS impacts, the monitoring activities also may address use and/or production of target fish species in the wetland or the development of wetland characteristics associated with suitable habitat (such as for spawning, foraging, or refuge) for target fish species. Monitoring elements may include vegetation cover data to demonstrate the attainment of a minimum cover of vegetation (as may be specified in a permit), or species composition data to evaluate the absence of nonnative or invasive species and the predominance of species associated with mature wetland communities of the desired type (USACE 1998). Vegetation monitoring can also quantify the amount of primary production for subsequent estimates of the production of fish and other aquatic organisms to replace losses. Aerial photography sometimes is used to identify certain vegetation types or unvegetated areas. Required monitoring also may include geomorphology and groundwater and surface water hydrology over the monitoring period to demonstrate the attainment of a specified hydrologic regime applicable to the wetland type desired. Under the requirements of the authorizing permit, monitoring may be required for 5 years or until the goals of the project are met (as for CWA Section 404 permits). Longer time spans may be required for complicated and/or larger sites (Perry et al. 2001).

The fluxes resulting from the marsh's primary production are very difficult to measure (Adam 1990). The in-situ production of fish biomass is a resulting component of the primary production of the marsh. An example of this type of estimate was presented by PSE&G (1999.) Field data from monitoring studies on fish abundance in weirs (marsh plain habitat) and otter trawls and push trawls (marsh channel habitat) were used to estimate the abundance and biomass of fish in the marshes. Production was estimated by multiplying the mean biomass for a species by the production-to-biomass (P to B) ratio for that species as estimated for Delaware Bay (Monaco 1995). The production of small fishes was then used to grow additional predator species (striped bass [*Morone saxatilis*], weakfish [*Cynoscion regalis*], and white perch [*Morone americana*]) using bioenergetics models for the predator species and site-specific information on growth, water temperatures, and energy density of fish.

Production estimates based on the capture of organisms in the marshes tend to underestimate actual production because trawls and weirs do not capture fish with complete efficiency. In addition, the trawls, weirs, and push nets employed in field studies do not effectively sample larger predatory fishes, such as white perch and striped bass. The bioenergetics approach similarly underestimates production. This approach accounts only for fish actually captured within the marshes or produced by predators feeding on fish produced in the salt marsh, but does not include production from detrital food webs, a source believed to be very important in the Delaware Bay.

A monitoring plan is developed at the time the project goals and objectives are defined and performance criteria for the successful restoration or creation are established. Performance criteria should be directly linked to the project goals. Measurable aspects of the restored system are evaluated against the performance criteria (Weinstein et al. 1997, 2000a, Weinstein 1998, Fell et al. 2000) to determine the progress of the system in meeting the goals. The spatial and temporal variation in fish and invertebrate communities should be considered in developing a monitoring plan (Desmond et al. 2002). Reference sites (as discussed above) are selected that reflect the undisturbed condition for the type of wetland being restored or created within the same ecological region and similar landscape setting.

Monitoring should be conducted before the restoration measures are implemented in order to determine baseline conditions, during implementation of the measures (implementation monitoring) to verify that the measures were correctly performed, and after completion of implementation (effectiveness monitoring) to determine if the restoration measures have achieved the desired results. Effectiveness monitoring should measure indicators that are directly tied to the project goals and that can be evaluated to determine which aspects of the restoration are functioning as planned. For example, the diversity and density of fish species associated with the wetland could be included in monitoring, particularly if species or use levels are identified in project goals to offset impacts of impingement and entrainment. Failure of a project to achieve the objectives of the restoration plan may require monitoring to determine if the restoration assumptions or the monitoring indicators were correct (validation monitoring).

Short-term monitoring goals may include absence of erosion or sedimentation, minimum acceptable hydrodynamic conditions, vegetation cover and diversity, absence of invasive species, and use by desired fish populations. Restored and created wetlands may also be monitored to identify changes in wetland quality or functions, such as erosion, insufficient growth of wetland species, or introduction of invasive species.

If the wetland is designed on the basis of ecological engineering, only minimal maintenance may be necessary. Maintenance may be required both during and after the initial monitoring period. During the early period of wetland development, before biotic community goals are met, maintenance activities may be required. However, depending on the design of the site, maintenance also may be necessary as a long-term requirement to ensure the continued success of the wetland. This maintenance may include repairing eroding areas, increasing populations of desired species, and removal of undesirable species. Methods that may be implemented through maintenance programs include herbicide application, prescribed burns, cutting, or the installation of erosion control materials. Prescribed burns are used in the long-term management of community types that are adapted to periodic fires. Burns are conducted frequently during early periods of community development (e.g., a 1- to 3-year interval) and at a decreased frequency for well-established native communities. Prescribed burns benefit native fire-adapted species and impede the growth and development of nonnative species.

An adaptive management approach greatly increases the potential for success of a wetland creation or restoration project. Adaptive management is a process for identifying and meeting environmental management goals by an iterative process of monitoring and engineering response (Holling 1978). This process is characterized by the systematic acquisition and application of reliable information for the purpose of improving management of natural resources over time (Wilhere 2002). The ultimate objective of adaptive management is sustainable management of ecosystems in the context of human development (Thom 1996).

In highly complex ecosystems that have very site-specific ecological processes, effective management can only be accomplished by obtaining and applying site-specific data (Haney and Power 1996, Walters and Holling 1990). This is particularly true for tidal wetlands, in which complexity is a function of, among other things, latitude, distance from the sea, local relative sea level rise, atmospheric and gravitational tidal effects, freshwater input, topography, substrate types, ecological history, and disturbance (Adam 1990, Kemp et al. 1992). Given the level of complexity in the ecology of tidal wetlands and our inability to completely understand the details of the functioning of these systems, adaptive management is the appropriate framework under which a successful large-scale environmental restoration can be conducted (Thom 1996).

Adaptive management closely ties management approaches and techniques to the monitoring program. Prescribed management actions may be modified, suspended if no longer needed, or new actions added to address changes in wetland characteristics. Consistent evaluation of the monitoring data enables a rapid response to threats that may develop (such as substrate erosion or invasion of nonnative species) by modifying prescribed treatments based on changes in site characteristics.

### *2.1.7 Advantages and Limitations*

Wetland creation, restoration, and banking would enhance fish populations and their invertebrate food base. Application of the current understanding of wetland creation and restoration methods, in conjunction with operation of a well-developed monitoring program, could result in effective compensation of losses from CWIS impacts. The advantages and limitations of wetland creation, restoration, and banking as an environmental enhancement are listed in Table 2-1.

**Table 2-1**
**Advantages and Limitations of Wetland Creation, Restoration, and Banking for Mitigating CWIS Operational Impacts.**

| Advantages | Limitations |
|---|---|
| Wetlands established for compensation can mitigate directly for losses.<br><br>Wetlands established for compensation may also provide numerous other benefits having publicly recognized value, including habitat for wildlife, water quality improvement, flood control, and recreation.<br><br>The value of the wetlands established will extend beyond the life of the impacting facility and provide long-term benefits.<br><br>The compensation for wetland impacts through wetland banking can be more cost-effective than the creation or restoration of wetlands and provide greater flexibility for fulfilling compensation requirements.<br><br>Banking may allow multiple parties with similar goals to complete mitigation requirements effectively, allow benefits of larger-scale projects, and provide immediate mitigation. | The species that benefit from the enhancement may be different than those that are impacted by CWIS (which may include undesirable species).<br><br>A long-term commitment to monitoring and maintenance of the wetlands may be required.<br><br>Although the availability of wetland banks including the desired wetland type may be widespread, wetlands benefiting the target fish species may not be available. |

### *2.1.8 Summary*

Wetlands perform important functions within the landscape, including functions that provide foraging and spawning habitat for fish and protection from predators, and that improve water quality both in the water body as well as the surface runoff entering the wetland, and benefit the aquatic food base.

Ancillary benefits that may result from wetlands restoration include (1) amelioration of the negative effects of flooding; (2) increased diversity of wildlife species of concern, such as migrating shorebirds, due to increased habitat; (3) increased recreational opportunities for both active (hunting and fishing) and passive (bird watching and nature study) activities; (4) environmental education; and (5) improved water quality.

The science of marsh ecology has made substantial advances since Teal (1962) published a paper proposing detrital export as a major contribution to estuarine and coastal productivity (e.g., see Weinstein and Kreeger 2000). The improved understanding of wetland ecology has allowed better planning, site selection, design, construction methodology, and monitoring of wetland creation and restoration projects. This improved understanding has also resulted in improved success in the creation and restoration of wetlands.

Created and restored wetlands have been shown to effectively support populations of many fish species, and the increased habitat could be used to offset impacts of CWISs. More importantly, by implementing the wetland creations and restorations through ecological engineering, these sites should provide their direct aquatic ecological and ancillary benefits long after the losses from the CWIS cease.

Key developments in wetland restoration science can be tracked through the American Fisheries Society Early Life History Section (at http://www2.ncsu.edu/elhs/–see *Stages* newsletter, or at www.marine.rutgers.edu/rumfs/elh.htm) and through the Estuarine Research Foundation (at http://erf.org or http://estuaries.org). In April 2003, Restore America's Estuaries (RAE) will sponsor a national conference in Baltimore, Maryland, at which many of the technical issues discussed in this section will be explored (www.estuaries.org).

## 2.2 Creation and Restoration of Submerged Aquatic Vegetation Beds

Submerged aquatic vegetation (SAV) performs a variety of roles in aquatic ecosystems, including serving as food, habitat, and/or shelter for a variety of waterfowl, fish, shellfish, and invertebrates. It contributes to important aquatic chemical processes, such as absorbing nutrients and oxygenating the water column. Dense beds of SAV also serve to attenuate wave energy and slow water currents, thereby allowing suspended sediments to settle out of the water column, reducing resuspension of sediments, and reducing erosion of shoreline areas. Seagrasses (estuarine and marine SAV) occur in all coastal states of the United States except for Georgia and South Carolina (where freshwater inflows, high turbidities, and tidal amplitudes inhibit their occurrence), and can be extremely productive habitats (Thayer et al. 1997).

The health of SAV habitats in many areas has been impacted by anthropogenic and natural causes. There have been large decreases in the presence of SAV in some areas where it historically occurred. Declines in the presence of SAV have been attributed to natural population cycles, weather events (e.g., droughts and hurricanes), overgrazing by fish and other biota, industrial pollutants, and agricultural herbicides. Increased turbidity (from sediments eroded into waterways and algal blooms caused by excessive nutrient inputs from agricultural and urban runoff) also has been implicated as a major cause for the decline in SAV abundance and distribution in Chesapeake Bay (Hurley 1991). Excessive physical disturbance of SAV from fishing gear and the propellers of vessels also can lead to declines in SAV abundance (Atlantic States Marine Fisheries Commission 2000).

Because of the ecological importance of SAV to many fish species (Hughes et al. 2002, Wyda et al. 2002, Heck et al. 1989 [see also Section 2.2.3]), the recovery of SAV in areas where it has declined may be a way of compensating for potential losses of fish due to impingement and entrainment from CWIS operations.

### *2.2.1 State of the Science and Current Use*

In recent years there have been considerable advances in understanding the interactions between environmental conditions and growth and survival of SAV, as well as improvements in the planning, site selection, and techniques needed to successfully plant and restore beds of SAV. Fonseca et al. (1998) stated that the ability to successfully plant SAV for restoration or mitigation purposes has progressed to the point that it should no longer be considered experimental. Fonseca et al. (1998) also reviewed 138 documents dated through 1995 that reported on field studies with seagrass and found that successful seagrass planting had occurred in all major regions of the United States.

Perhaps the best-known SAV restoration effort (and the effort with the longest history and greatest scope) has been a recovery program in the Chesapeake Bay. This regional restoration effort had its beginnings in research initiated by the Virginia Institute of Marine Science in 1978 as an experimental program with eelgrass. Since then, the restoration program has evolved into a baywide, multiagency effort that has been successful in getting SAV established in many areas of the Chesapeake Bay watershed (Orth 2002a,b, VIMS 2002) and has an interim goal to restore 114,000 acres with SAV baywide (Chesapeake Bay Program 2000).

At the national level, the National Estuary Program was established in 1987 by amendments to the CWA to identify, restore, and protect nationally significant estuaries of the United States. To accomplish these goals, the National Estuary Program targets a broad range of issues, including SAV restoration, in the 28 estuary programs under its purview (USEPA 2001b). For example, the Tampa Bay (Florida) Estuary Program has a goal of restoring 12,350 acres of seagrass habitat and preserving an additional 25,600 acres (Tampa Bay Estuary Program 2000).

### 2.2.2 Methods for Restoring and Establishing SAV

In general, restoration of SAV habitats involves protecting remaining vegetation from impacting factors in order to allow recovery to proceed naturally, planting (i.e., transplanting raised plants, transplanting plants from another location, or using seeds), or both. If the reduced condition of the SAV is due to water quality degradation, recovery efforts through protection or planting will likely be unsuccessful unless the water quality impacts are addressed first. Addressing that issue may require action throughout the entire watershed and can be an extremely large and costly undertaking. For example, declines in historic abundance of SAV in Chesapeake Bay since the 1930s has been primarily attributed to decreasing water clarity as a result of nutrient input (which increases the abundance of algal blooms) and sediment inputs (which reduce light penetration in the water column). In recognition of this problem, one major focus of the Chesapeake Bay Program has been to restore suitable conditions in the watershed through such activities as stream restoration, creation of forested stream buffers to reduce erosion and capture excess nutrients, and requiring management practices that reduce sedimentation or agricultural runoff. These efforts may have contributed to the recent success that has been achieved in SAV planting and restoration in some areas of the bay.

Once water quality issues are addressed, SAV restoration efforts may be undertaken. If the goal is to restore an area in which there is already some SAV present, efforts can focus on addressing physical factors that are preventing the optimal growth and survival of the SAV. Examples of physical factors that might contribute to SAV decline include disturbance of the SAV areas by fishing gear or fishing practices (e.g., trawling or clam or scallop dredging), boat propellers, or overgrazing by various biota (e.g., waterfowl or sea urchins). Methods for evaluating and correcting such disturbances are addressed by the Atlantic States Marine Fisheries Commission (2000) and typically include various measures for controlling access to the SAV areas or relocating the disturbing activities. One common means for trying to reduce grazing by biota is to put exclosures around the SAV area until the health of the beds has improved. The length of time required for such recovery will depend upon the species of SAV and the portions of the plants (e.g., reproductive versus non-reproductive tissues) that are affected (Table 2-2). It may also be important to consider the types of fish species likely to be attracted to a particular type of SAV, since the differences in structural features among species may affect the types of fish that will be attracted and supported.

If the goal is to restore an area where SAV is not present, it is essential that adequate consideration be given to identifying a suitable location and appropriate SAV species for that location. Fonseca et al. (1998) identified site selection as the most important step in the SAV restoration and mitigation process. Some important factors to consider when evaluating the suitability of a planting location and deciding which SAV species a site is suitable for include:

- Timing and duration of immersion (related to elevation),
- Sediment stability and thickness,
- Nutrient conditions,
- Turbidity, salinity, and temperature regimes,

**Table 2-2**
**Estimates of Relative Ability of Selected SAV Species to Recover from Injuries to Key Features and Overall Estimates for Injury Recovery Potential.**

| Species | Injury Recovery Potential | | Overall Intrinsic Recovery Potential |
|---|---|---|---|
| | Asexual Injury (to meristems) | Sexual Injury (to reproductive structures) | |
| *Zostera marina* (eelgrass) | Moderate | Moderate and variable | Moderate |
| *Halodule wrightii* (shoalgrass) | High | Low | High |
| *Ruppia maritima* (widgeon grass) | Moderate | High and variable | High |
| *Thalassia testudinum* (turtlegrass) | Low | Low and variable | Low |
| *Syringodium filiforme* (manatee grass) | Moderate | Moderate | Moderate |
| *Halophila* spp. | High | Very high | High |
| *Vallisneria americana* (wild celery) | Low | High | Moderate |
| *Potamogeton perfoliatus* (redhead grass) | Moderate | Moderate | Moderate |
| *Potamogeton pectinatus* (sago pondweed) | Moderate | High | Moderate |
| *Zanichellia palustris* (horned pondweed) | High | High | High |
| *Elodea canadensis* (common elodea) | High | High | High |

Source: Atlantic States Marine Fisheries Commission (2000).

- The amount of wave action the site is exposed to, and
- The exposure to grazing fauna that might feed on the SAV.

Ultimately, if SAV is not currently present at a location, it is important to carefully consider pertinent factors that will influence the success of an effort to establish SAV there.

A number of methods have been used to plant SAV. The most common and successful methods include planting plugs (cores of seagrass, rhizomes, and sediments taken from another location), stapling rhizomes of transplanted plants in place, transplanting shoots in peat pots, and sowing seeds (Fonseca et al. 1998). In some cases, fertilizer has been added to sediments before or after planting in order to improve planting success, but the results have been mixed. Additional details on these and other planting methods are reviewed by Fonseca et al. (1998). Some other considerations that may affect the difficulty of planting SAV include water depth, sediment type, and exposure of the area to wave action.

### 2.2.3 Applicability for Mitigating CWIS Operational Impacts

For many fish species, SAV is considered important for maintaining population levels either by providing spawning and nursery habitat for valuable game and commercial fish or for their prey. Laney (1997) conducted a limited review of the use of SAV by 33 species of fish and invertebrates important to fisheries along the east coast of the United States and found that most of those species had some level of dependence on SAV habitat (Table 2-3). The South Atlantic Fishery Management Council (1997) clearly identified that SAV is considered an important resource, both ecologically and economically. Hughes et al. (2002) found that loss of SAV in two New England estuaries resulted in decreased diversity of the fish community. The potential for SAV restoration to benefit fish by affecting survival, production, growth, and reproduction is discussed below.

***Survival.*** It is a well-studied phenomenon that as the structure of aquatic vegetation increases (at least up to a point), the predation-risk of small-bodied fishes from larger piscivorous fishes is reduced. In fact, predation avoidance is probably a major factor that leads to the higher densities of fish and invertebrates commonly observed in vegetated habitats. Hughes et al. (2002) also found that the species most seriously affected by eelgrass loss in southern New England were small-bodied forage fish. Many studies have examined the effects of predation risk (and foraging success) on vegetation use by fish (e.g., Hayse and Wissing 1996, Savino et al. 1992, Gotceitas 1990a,b, Holbrook and Schmitt 1988, Rozas and Odum 1988). Increased survival of fish, especially smaller fish such as larvae and juveniles, could lead to increases in population levels by improving recruitment. Therefore, the development of additional SAV habitat in areas where such habitat is limited may be a viable option to compensate for losses of fish from CWIS operations.

***Fish Production and Growth.*** It is clear that the density of many types of fish and invertebrate prey is often higher in habitats containing SAV than in surrounding habitats containing less structure (e.g., Wyda et al. 2002, Hughes et al. 2002). In a review of the ecology of seagrass meadows of the western coast of Florida, Zieman and Zieman (1989) cited a number of studies that reported higher densities of invertebrates and fish in SAV than in other surrounding habitats. As discussed above, there are many studies (e.g., Hayse and Wissing 1996, Savino et al. 1992, Gotceitas 1990a,b, Holbrook and Schmitt 1988, Rozas and Odum 1988) that address hypotheses about whether fish utilize SAV primarily because it increases survival by reducing the risk of predation or whether it provides a richer source of food.

**Table 2-3**
**Use of SAV by Selected Fish and Invertebrate Species Important to Fisheries on the Eastern Coast of the United States.**

| Species | Use of SAV Habitat |
|---|---|
| Alewife (*Alosa pseudoharengus*) | Direct use of SAV probably low, but possibility of some spawning in SAV. |
| American eel (*Anguilla rostrata*) | Yellow stages occur in SAV during the estuarine phase of their life history; probably not obligate SAV users. |
| American lobster (*Homarus americanus*) | Preferred settling habitat for larvae. |
| American shad (*Alosa sapidissima*) | Direct use of SAV probably low, but information about early life stages is limited. |
| Atlantic croaker (*Micropogonius undulatus*) | Juveniles use SAV beds in spring and early summer. |
| Atlantic herring (*Clupea harengus*) | Some level of trophic linkage likely, but direct use of SAV is not extensive. |
| Atlantic menhaden (*Brevoortia tyrannus*) | Detrital SAV used as a food source. |
| Atlantic sturgeon (*Acipenser oxyrhynchus*) | Some linkage likely for juveniles, but dependence is probably limited. |
| Bay scallop (*Argopecten irradians*) | Adults prefer to inhabit SAV beds and juveniles will preferentially settle in SAV if the stem density is not too high. |
| Black drum (*Pogonias chromis*) | Do not appear to be heavily reliant on SAV. |
| Black seabass (*Centropristis striata*) | Juveniles use SAV, but dependence on SAV as nursery areas uncertain. |
| Blue crab (*Callinectes sapidus*) | Use SAV, when available, as foraging habitat and as refuge for molting adults. |
| Blueback herring (*Alosa aestivalis*) | Direct use of SAV probably low, but possibility of some spawning in SAV. |
| Bluefish (*Pomatomus saltatrix)* | Some linkage is likely through prey, but little direct use. |
| Brown shrimp (*Penaeus aztecus*) | Juvenile recruitment rates are high near SAV; SAV is important for shrimp in some areas, but adults are not obligate SAV users. |
| Hickory shad (*Alosa mediocris*) | Direct use of SAV probably low, but information about early life stages is limited. |
| Northern shrimp (*Pandalus borealis*) | Some limited use of SAV appears likely. |

**Table 2-3 (Cont.)**

| Species | Use of SAV Habitat |
|---|---|
| Pink shrimp (*Penaeus duorarum*) | Highly reliant on SAV as nursery habitat and are not abundant in areas where SAV is absent. |
| Rainbow smelt (*Osmerus mordax*) | May spawn on SAV; and juveniles may use SAV as nursery habitat. |
| Red drum (*Sciaenops ocellatus*) | Very dependent during juvenile phase; larvae use SAV beds spring-summer. |
| Scup (*Stenotomus chrysops*) | May use SAV as foraging habitat, but extent of use not well known. |
| Southern flounder (*Paralichthys lethostigma*) | Juveniles may use SAV. |
| Spanish mackerel (*Scomberomorous maculata*) | Not directly associated with SAV, but rely heavily on prey that use SAV. |
| Spot (*Leiostomus xanthurus*) | Juveniles use SAV as refuge and for food resources. |
| Spotted seatrout (*Cynoscion nebulosus*) | Spawns in SAV; juveniles use SAV as nursery areas; maximum abundance is in areas where SAV is abundant. |
| Striped bass (*Morone saxatilis*) | Not highly dependent; some prey species are dependent on SAV. |
| Striped mullet (*Mugil cephalus*) | Appear to be closely linked with SAV, feeding on epiphytes and, possibly, directly on SAV. |
| Summer flounder (*Paralichthys dentatus*) | SAV beds are important to juveniles and adults. |
| Tautog (*Tautoga onitis*) | Both adults and juveniles use SAV on a seasonal basis for spawning, foraging, and cover. |
| Weakfish (*Cynoscion regalis*) | Both juveniles and adult forage in and adjacent to SAV beds in areas where SAV is present; alternative habitats used in Georgia and South Carolina where SAV is not present. |
| White mullet (*Mugil curema*) | Juveniles use eelgrass beds in spring and early summer. |
| White shrimp (*Penaeus setiferus*) | Does not appear to rely heavily on SAV. |
| Winter flounder (*Pleuronectes americanus*) | Juveniles may forage in and near SAV beds, but growth rate in SAV appears to be lower than in other available habitats. |

Source: Laney (1997).

***Reproduction.*** While many studies have reported on the occurrence of juvenile and adult fishes in SAV, relatively few studies have dealt with the settlement in and use of SAV by larval fishes. In Chesapeake Bay, for example, seagrass beds are important for fish that brood eggs (e.g., silverstripe halfbeak, *Hyporhamphus unifasciatus*) and for fishes with demersal eggs (e.g., rough silverside, *Membras martinica*) (Thayer et al. 1997). Fish that spawn in the Chesapeake Bay area during winter and early spring are unlikely to require seagrass habitat for spawning because SAV naturally dies back during that period. However, larvae of fish that spawn during spring through summer would likely utilize SAV as nursery areas. Species that have larvae present during this period and that are known to use SAV habitats include anchovies (*Anchoa* spp.), northern pipefish (*Syngnathus fuscus*), weakfish (*Cynoscion regalis*), southern kingfish (*Menticirrhus americanus*), red drum (*Sciaenops ocellatus*), silver perch (*Bairdiella chrysoura*), rough silverside, feather blenny (*Hypsoblennius hentzi*), and halfbeaks (Thayer et al. 1997).

In other regions, larval use of SAV may be somewhat different from that observed in Chesapeake Bay because of differences in SAV growing patterns and fish spawning seasons. Thayer et al. (1997) indicated that SAV is present almost year-round in some areas of North Carolina, and larval and early juvenile fishes are present in those SAV beds during much of the year. Some important commercial and sport fish such as gag grouper (*Mycteroperca microlepis*), snapper (*Lutjanus griseus*), seatrout or weakfish (*Cynoscion* sp.), bluefish (*Pomatomus saltatrix*), mullet (*Mugil* sp.), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonius undulatus*), flounder (*Paralichthys* sp.), and herrings (Clupeidae) utilize SAV in that area. Whereas the Atlantic States Marine Fisheries Commission (1997) recognized that all of the species managed by it are dependent upon SAV habitat to some degree, economically important species that use SAV habitats primarily for nursery and/or spawning grounds include spotted seatrout, grunts (Haemulids), snook (*Centropomus* sp.), bonefish (*Albulu vipes*), tarpon (*Megalops atlanticus*) and several species of snapper and grouper.

Although juvenile fish and shellfish often can use other types of habitat, the bulk of the shelter in many estuarine systems is provided by SAV, and the loss or reduction of this habitat will lead to declines in juvenile fish settlement (Thayer et al. 1997). In areas where the availability of SAV habitat is limited, restoring and planting SAV habitat may be one means for increasing the availability of spawning and nursery areas to the benefit of many fish species. This may be especially useful in some estuarine areas where SAV habitat has been declining because of development-related impacts to watersheds. However, it should be noted that water quality factors that limit the growth of SAV in a watershed may need to be addressed before initiating, or as part of, SAV restoration projects.

One issue pertinent to using SAV as a mitigation approach is the determination of how much SAV must be provided to compensate for a particular fish loss from CWIS. Quantitative methods for making such determinations include both empirical and modeling approaches. The usefulness of a particular approach would likely be related to the function that SAV habitat provides for the species of concern. Ways to evaluate the appropriateness of particular enhancement types and desired compensation levels are discussed in greater detail in Section 4.4.

### *2.2.4 Cost*

The costs of restoring SAV habitats vary widely depending upon the methods used, the type of vegetation being restored, and the environmental setting in which the work is conducted.

Although the ultimate cost of a project is largely driven by the area to be restored, Fonseca et al. (1998) identified a number of other factors that often lead to increased costs:

1. Inappropriate site selection,
2. Inexperience (inefficiency, poor technique),
3. High site disturbance (e.g., grazing or boat wash),
4. Water depths that require use of SCUBA divers,
5. Low visibility,
6. Soft sediments (especially when wading or walking on the site is required),
7. Rough seas,
8. Cold water planting,
9. Capital costs (purchasing equipment: e.g., boats, motors),
10. Wide profit margins of contractors,
11. Amount of site preparation required (e.g., creation of subtidal dikes),
12. Excessive monitoring frequency, and
13. Selection of overly detailed monitoring parameters (e.g., blade width, length, faunal assessment).

Fonseca et al. (1998) also conducted a detailed review of costs associated with SAV restoration and planting. They identified cost estimates ranging from $19,000 to $127,000 per acre (average cost was $37,000 per acre) but concluded that many of the cost estimates did not accurately reflect some of the expenses (e.g., planning and monitoring costs) that would be incurred during a restoration or mitigation project. The average cost was somewhat similar to the costs of planting salt marsh vegetation if monitoring and design costs are excluded (see Section 2.1). The authors included a detailed cost estimate for an example project to restore an area of SAV damaged by propeller scarring. Their estimate, which included planning, planting, monitoring, report-writing, and a contractor profit of 10%, came to a total cost of $206,000 per acre.

Recently, the Seagrass Restoration Program at the Virginia Institute of Marine Science reported encouraging results from using seeds to initiate growth of SAV in experimental plots

(Orth 2002a,b). It is likely that using seed instead of transplanting plants would be a cheaper alternative for establishing SAV in some cases.

### 2.2.5 Monitoring and Maintenance

#### 2.2.5.1 Monitoring

The purpose of planting and restoring SAV is to establish viable plant communities that perform habitat functions equivalent to natural SAV, and measures of project success should be tied to those functions. However, the evaluation of all seagrass ecosystem functions (e.g., sediment stabilization, biomass production, nutrient cycling, and secondary production) is almost always beyond the resources of any project. Many habitat functions (e.g., animal abundance, taxonomic composition, complexity of the seagrass canopy, macroalgal abundance) appear to be related to area coverage and persistence of that coverage, two parameters that can be inexpensively monitored (Fonseca et al. 1998). Some typical aspects to monitor in order to evaluate the success of SAV restoration efforts include:

- Survival (number and proportion of original plants that survive from year to year),
- Coverage (the size of the area containing vegetation and the percent coverage within a unit area), and
- Number of shoots (number of individual plants or stems within a given area).

Fonseca et al. (1998) recommends that monitoring should be conducted at least quarterly for the first year after planting. Subsequent monitoring should be conducted biannually thereafter for at least four additional years. If replanting is required, the initial year's monitoring regime should be reinitiated. In some cases, restoration efforts within a particular area will not be successful. All projects should have a mechanism in place to decide when a particular planting site is to be considered unsuccessful so that efforts can be discontinued and moved to another location. Fonseca et al. (1998) recommend that only rarely should additional replanting be allowed on a site after two previous attempts.

In addition to monitoring the success of SAV establishment, some projects also monitor use of the SAV by particular types of organisms. It is clear that this type of monitoring will add to the overall cost of the project and, although variable, some cost estimates are provided by Fonseca et al. (1998). Because the purpose of an SAV project would be to provide compensation for fish losses due to CWIS operations, monitoring of some faunal parameters, such as fish abundance, species composition, density of larval fishes, growth rates, survival rates, or occurrence of reproduction, may also be desirable.

#### 2.2.5.2 Maintenance

Under ideal conditions, once it is planted, an SAV bed will become well established, will be self-sustaining, and may actually increase in size over the planted area. If this happens, little to no maintenance will be required. However, if monitoring identifies deficiencies in growth and establishment of planted SAV, it may be necessary to replant some areas. The monitoring process should first be used to help identify the potential reasons (e.g., water quality issues, herbivory or physical disturbance) that the plantings did not become established. Appropriate action should then be taken to address problems.

### *2.2.6 Advantages and Limitations*

Development and restoration of SAV beds have been successful in some areas (e.g., some SAV beds have been increasing in Chesapeake Bay). As a consequence of past research and mitigation efforts, there are well-established procedures and techniques for planning, planting, and monitoring SAV projects. In addition, new methods, such as planting with seed instead of transplanting young plants, are being investigated and may make it easier and cheaper to develop SAV habitats in the future. It is important to note that prior to initiating a SAV restoration project, anthropogenic impacts to watersheds that led to decline in historic SAV beds may need to be addressed. Some advantages and limitations of SAV restoration and enhancement as a means for mitigating CWIS impacts are provided in Table 2-4.

**Table 2-4**
**Advantages and Limitations of Creation and Restoration of SAV as a Mitigation Tool for CWIS Operations.**

| Advantages | Limitations |
|---|---|
| Well-established ecological benefits associated with SAV habitat; including increased survival, recruitment, and growth of some fish species.<br><br>Successful restoration likely to benefit invertebrates and fish; may also benefit other wildlife species (e.g., waterfowl).<br><br>Once established, SAV beds may reduce resuspension of sediments and erosion of shorelines by reducing currents and wave strength.<br><br>Well-established methods exist for planting and establishing SAV habitat.<br><br>Typically only 1-2 years required to implement. | Additional planting may be required if not initially successful.<br><br>Establishment of recovered SAV habitat may take many years, depending on planting success and the species to be recovered.<br><br>May be difficult to establish SAV if anthropogenic impacts to watershed (e.g., sediment inputs, nutrient loading, runoff of herbicides from agricultural fields) are not addressed first.<br><br>May be necessary to control wildlife use of SAV (e.g., grazing by waterfowl) until it becomes well-established.<br><br>In some cases, the fish that directly benefit from establishing or restoring SAV may not be the species most affected by CWIS operations. However, there may be indirect benefits to such species. |

### 2.2.7 Summary

SAV is an ecologically significant habitat providing food, refuge, and spawning areas for many fish species. Because of human impacts and natural changes, SAV has declined or completely disappeared from some areas where this habitat historically occurred. In such areas, restoring or increasing the amount of SAV habitat may greatly enhance population levels of some fish species. For these reasons, enhancement and restoration of SAV habitat could be a viable means to improve fisheries in some locations and could serve as a viable enhancement strategy to mitigate for impingement and entrainment impacts.

## 2.3 Creation of Artificial Habitats

### 2.3.1 State of the Science and Current Use

Artificial habitats (including artificial reefs) are structures or materials that are placed in aquatic systems (freshwater or marine) to enhance or create habitat for fish or other aquatic organisms. Artificial habitats for fish are currently in use in most, if not all, of the 50 states and are also widely used in other countries, especially in Europe and Asia. Japan is sometimes considered to be a world leader in research related to the use of artificial habitats in marine environments (Baine 2001). While a large proportion of artificial enhancements for fish are geared toward marine environments, in a survey of state agencies and Puerto Rico conducted by the Reservoir Committee of the Southern Division of the American Fisheries Society (Southern Division AFS Reservoir Committee 2000), 82% of the states surveyed reported the use of artificial habitat enhancements in freshwater environments. Many states have formal artificial reef programs.

Interest in development of artificial habitats and in the technologies related to enhancing aquatic ecosystems is high in many areas of the world and is largely driven by organizations and individuals involved in subsistence, commercial, and recreational fishing. In addition to the interests of fishery users, there is also a great deal of interest in the uses of artificial habitats for fisheries management, environmental preservation, and mitigation. A great deal of research and development has been conducted on the technological aspects of artificial habitat construction, materials, and deployment. Furthermore, an extensive body of scientific literature exists on the effects of artificial habitats on fisheries and ecological parameters (for example, see Seaman and Sprague 1991, DeMartini et al. 1994, EARRN 1999). The level of knowledge and ongoing research related to various aspects of artificial reefs has grown to the point that some consider it to be a distinct multidisciplinary branch of fisheries science (Seaman and Sprague 1991).

The technology associated with artificial habitat design ranges from simple placement of brush piles, to sinking surplus ships, to placement of specially designed structures composed of various materials. In Texas, a program known as “Rigs to Reefs” recycles obsolete petroleum platforms into permanent artificial reefs rather than taking them ashore as scrap. To date, 49 oil rigs have been donated by oil companies (Texas Parks and Wildlife 2002). The choice of materials and types of structures best for use as artificial habitat will depend upon the desired function of the proposed habitat, the compatibility of various materials with the environment in which it is to be placed, the durability and stability of the materials, and the availability of the materials (Gulf States Marine Fisheries Commission 1997).

### *2.3.2 Applicability for Mitigating CWIS Operational Impacts*

Construction of artificial habitats as a means of enhancing, restoring, or mitigating for habitat degradation or loss is not a new idea (see Grove 1982, Barnett et al. 1991, Foster et al. 1994, Cheney et al. 1994, Carter et al. 1985a,b, Davis 1985, Ambrose 1994a). Developing artificial habitats has the potential to address concerns regarding impingement and entrainment losses of eggs or fish by providing refuge, foraging, spawning, or nursery habitats. Providing these additional habitats could result in increased survival, growth, body condition, or production of target fish species. In addition to providing these potential benefits to fishery resources, indirect benefits of artificial habitat construction may include increased local biodiversity, increased habitat availability or suitability for organisms other than fish (e.g., plants and invertebrates), increased food for fish and wildlife, and increased recreational opportunities, such as fishing or diving.

***Survival.*** One of the principal goals of many artificial habitats is to provide cover for adult or juvenile fish, with the idea that providing cover will enhance survival. Structural refuge on natural reefs has been shown to enhance the survival of new recruits (Carr and Hixon 1995), and it is reasonable to assume that artificial structures will also enhance survival over nonstructured habitat in many cases. However, it is also well known that predatory fishes are often attracted to artificial structures, perhaps because the structures serve to concentrate certain prey species. Artificial structures also often serve as a focal point for anglers seeking the attracted species. In some cases, overfishing of desirable species may occur, resulting in undesirable impacts to those species (Seaman and Sprague 1991).

***Fish Production and Growth.*** It is important to note that the deployment of artificial structures may not lead to overall increased production (i.e., numbers or biomass) of fish in a system as a whole. Although artificial structures commonly work well in increasing the numbers of fish within the vicinity of the structures, it is unclear in some cases whether these localized increases represent additional numbers of fish in the system as a whole or whether the structures are simply attracting and concentrating fish from other areas within the system. A considerable amount of scientific discussion has developed around this topic (e.g., Seaman 1997, Lindberg 1997, Grossman et al. 1997, Johnson et al. 1994, Wilson et al. 2001), and it has been identified by reef managers as one of the most important areas of needed research (Steimle and Meier 1997). The key to resolving this issue is to determine whether the production of fish within a particular system is either recruitment-limited or habitat-limited (Grossman et al. 1997).

In a recruitment-limited system, there is more habitat available than can be occupied by the number of new fish being produced. Adding artificial habitat to a recruitment-limited system would not be expected to lead to an increase in total population size (Grossman et al. 1997). However, adding structural features (e.g., artificial reefs) in an area predominated by nonstructured habitat (e.g., sand or mud bottoms) may well lead to increases in the production of species that are typically associated with structured habitats because it provides additional habitat in a habitat-limited system.

In habitat-limited systems, there are more young fish being produced than the available habitat can support. Under such conditions, it is expected that total population size will increase as the amount of habitat is increased, and production may well be improved by adding artificial habitat. For such additions to be effective, the habitat requirements of the fish species being mitigated for must be adequately understood to be incorporated into the design of the artificial habitat (i.e., the measures taken need to be focused on the target species).

It is clear that many fish species feed and grow while they are associated with constructed habitats. For example, quantitative estimates of fish production on the Torrey Pines Artificial Reef in Southern California were made by several different methods, including mark-and-recapture, feeding observations, and gut content analyses (DeMartini et al. 1994, Johnson et al. 1994). Data for 11 species indicated a production of 650 kg/ha over a seven-month growing season. Although this should be considered a rough estimate with many uncertainties, it indicated that some fish will reside on a constructed reef for a long period of time and that those fish will successfully feed and grow while on the reef. Moreover, fish production on the constructed habitat was estimated to be about nine times higher per unit area than production on the surrounding sand bottom, indicating that constructing the habitat greatly increased production over what it would have been had the area remained a sand bottom.

***Reproduction.*** The online *Habitat Manual for Use of Artificial Structures in Lakes and Reservoirs* (Southern Division AFS Reservoir Committee 2000) reported that surveys conducted of state agencies found that 29% of the respondents included the development of spawning habitat as a goal for artificial structures in lakes and reservoirs. The ability of artificial habitats to support fish spawning activities and the potential for this technology to mitigate entrainment of fish eggs and larvae will depend upon a number of factors, including the species of concern, the quantity and nature of existing habitat in the surrounding areas, and the specific type of artificial habitat being considered. It has been demonstrated that some fish species spawn on artificial habitats. For example, Marsden et al. (1995) and Marsden and Chotowski (2001) found that lake trout spawned on constructed habitat (rock piles) in the Great Lakes, and Stephens et al. (1994) inferred spawning of several species on an artificial reef based upon the appearance of larval fish of species that do not produce drifting larvae.

It is reasonable to expect that many fish species that have demersal eggs (eggs deposited on the substrate) may also spawn on artificial habitats. Since the types of fish eggs that are likely to be entrained by CWIS operations are often pelagic in nature, artificial habitats may not provide the best means for compensating for such losses. However, it is known that some fish species that produce pelagic eggs congregate around structures, including artificial reefs, during spawning. It is possible that strategic location of appropriate artificial habitat in areas away from or down-current of intake structures could promote spawning in areas where eggs will not be as likely to be entrained.

Different types of artificial habitats will (1) develop different types of fish communities; (2) support different life stages (i.e., larval, juvenile or adults); and (3) support various functions (i.e., feeding, spawning, or nursery habitat). The composition of the fish community can also be affected by the environmental setting (e.g., surrounding substrate), the age of artificial structures, and the habitat complexity of the artificial structure (Charbonnel et al. 2002, Coll 1998, Shermann et al. 2002). Thus, it is important to consider a number of variables when planning for and designing artificial habitats. If an artificial habitat is being considered for habitat mitigation, it is important to identify the ecological functions provided by the habitat being replaced, and, if possible, provide artificial habitat that will provide similar functions. In many cases, however, it is more feasible and, perhaps, desirable, to provide artificial habitat that will serve a different ecological function. Ultimately, resource managers must consider whether artificial habitat technology can be used to repair or replace damaged habitat function or replenish specific elements of the overall resources of an area (Atlantic and Gulf States Marine Fisheries Commissions 1998). In addition to ecological considerations, an array of non-ecological issues will need to be considered in planning artificial habitats. These issues include social, economic, engineering, and regulatory considerations. Additional discussion of these issues can be found in the *Artificial Reef Planning Guide* developed by the Atlantic and Gulf States Marine Fisheries Commissions (1998).

If the creation of artificial habitat is to be used as a mitigation measure, it will be necessary to determine how much habitat must be created to compensate for a particular fish loss from CWIS. Quantitative methods for making such determinations include both empirical and modeling approaches. However, it might be necessary in some cases to base the type and amount of habitat to be created on professional judgment and negotiation. The usefulness of a particular approach would likely be related to the function that the proposed habitat provides for the species of concern. Means for evaluating the appropriateness of particular enhancement types and desired compensation levels are discussed in greater detail in Section 4.4.

### *2.3.3 Cost*

Ultimately, the costs associated with the development of artificial fish habitat will depend on the type and size of habitat to be constructed, the environmental setting for the proposed habitat, the ecological goals of the project, and the materials selected for use. Construction costs for development and placement of simple artificial structures, such as rubble piles or bundles of brush in a small area, may be quite low; costs of engineered structures or placement of surplus ships may be considerable. Some important considerations when developing costs-benefit comparisons of potential artificial habitat designs include the size of the artificial habitat area that will need to be developed, the costs of materials to be used, and the durability and stability of those materials in the environment of concern. When cost estimates of various materials are being developed, it is important to consider the overall cost/unit area, including preparation, deployment, and maintenance of the materials. For example, many artificial reefs have been constructed from surplus vessels that are often donated to the project. However, there would be costs associated with preparing these vessels before they are deployed. For example, there would be costs associated with cleaning and removing hazardous materials such as petroleum-based products, lead-based paint, polychlorinated biphenyls (PCBs), and asbestos. Structures constructed specifically for use as artificial habitat may actually be cheaper in some cases after all expenses are taken into account.

Some specific examples of costs for constructing artificial habitats are provided below:

- In one case, it was estimated that 200 to 300 acres of artificial habitat would be required to compensate for lost fisheries functions due to contamination (Ambrose 1994b). The cost was estimated at approximately $29 million to construct an appropriate deep water reef designed to provide nursery habitat for fish (mixed low-relief and high-relief habitat created using quarry rock). As an alternative, a 240-acre shallow-water rock reef with kelp forest was estimated to cost approximately $41 million to construct Ambrose (1994b).
- The costs of planning, construction, monitoring and research for a 300-acre artificial kelp reef to mitigate for cooling water impacts from the San Onofre Nuclear Generating Station are expected to total approximately $50 million since its inception in 1991. The estimated budget for independent monitoring and technical oversight of the kelp reef development by the California Coastal Commission during FY 2002-2003 was approximately $1.6 million (CCC 2001).
- The USEPA (2001a) projected on the basis of information from 15 oyster reef restoration studies that oyster reef restoration as a means of compensating for impingement and entrainment losses would cost approximately $6,038/hectare.
- Janvrin (2002) estimated costs for the creation of spawning, over-wintering, and juvenile habitats needed to restore habitat loss within the upper Mississippi River system through the use of fish cribs, spawning reefs, over-wintering structures, and so forth. The estimated costs were almost $1.8 million per mile, with annual operation and maintenance costs estimated at nearly $16,900 per mile.

### *2.3.4 Monitoring and Maintenance*

#### 2.3.4.1 Monitoring

As identified by the National Marine Fisheries Service (NMFS 2002), the primary reasons for establishing monitoring programs as part of artificial reef management are to (1) assure compliance with the conditions defined in any authorizing permits or other applicable laws or regulations; and (2) provide an assessment of the predicted performance of reefs. Specific monitoring strategies selected should depend on compliance requirements, ecological goals for the habitat construction, the type of artificial structure that needs to be evaluated, and the availability of resources (e.g., funding and personnel). Some considerations for compliance and performance monitoring of artificial habitat projects are provided below.

***Compliance Monitoring.*** Specific compliance monitoring requirements and the degree to which federal, state, or local agencies carry out compliance inspections will be determined by governing law, regulations, and conditions for approval of the various required permits (e.g., permits for U.S. Coast Guard [USCG], USACE, and state agencies).

Compliance monitoring may involve documentation of material stability and structural integrity of the artificial habitat. Typical methods for determining these parameters may include use of simple bathymetric surveying instrumentation, such as hull mounted depth recorders or more sophisticated gear, such as side-scan sonar or magnetometers for mapping the positions of artificial habitat materials. Compliance monitoring surveys may often require the use of visual confirmation of habitat material obtained through observations provided by SCUBA divers, cable-controlled cameras, or remotely operated vehicles with cameras.

***Performance Monitoring.*** Performance monitoring involves periodic evaluations to determine whether a specific artificial habitat project is accomplishing the purposes for which it was established. This type of monitoring should also be designed to detect whether the habitat is having unexpected negative consequences, to help identify research priorities, and to identify whether alternative management strategies or new regulations may be needed. Ultimately, performance monitoring assesses the engineering, biological, and socioeconomic factors essential in documenting the success or impact of a given artificial habitat project. Baseline data should also be collected before creating artificial habitats. These data would form the basis for the comprehensive evaluation of impacts and performance of the artificial habitat (Wildling and Sayer 2002).

The long-term success of artificial habitats is largely dependent on materials remaining in place and continuing to provide durable, safe, and effective substrate for the establishment of a biotic community. Certain materials and construction methods will be better suited for applications in specific aquatic environments (e.g., freshwater versus marine waters; offshore versus nearshore versus estuarine), and some will be found not to meet acceptable standards for continued use. Engineering assessments provide a means to evaluate the structure and learn from the efforts of both past and present habitat construction activities, thereby allowing for improvements in future habitat development techniques.

Because most artificial habitat projects are constructed for ecological or fisheries purposes, detailed biological assessments of the positive and negative impacts should be conducted. In most cases, this can be done through underwater observations and collection of data during routine monitoring activities. Such monitoring can provide a great deal of information regarding the biotic community that develops and can track whether the artificial habitat is successful in producing both short-term and long-term enhancements of desired fish populations. Depending on the goals of the project, quantifiable data may be collected regarding important ecological aspects, including development of vegetation and sessile invertebrate communities; interactions between fish associated with structures and the biological communities in surrounding habitats; the association of target fish species with certain structures; evidence of spawning, recruitment, and survival of target species; and long-term changes in biotic community structure. Biological monitoring of artificial habitats is also critical in identifying research priorities for gaining a better understanding of how artificial habitats work and how they can be best used to meet fisheries management objectives. It may be necessary to identify and use measurements in appropriate reference areas to establish a baseline against which biological success of an artificial habitat project can be evaluated.

While artificial habitats are constructed for various reasons, the most commonly encountered use of such structures is to enhance fishing activities. Therefore, the measurement of the success of a given project may include evaluations of the effects of the project on the fishery it was designed to enhance. As identified in Section 2.3.2, there has been a great deal of concern that many artificial structures serve only to attract and concentrate individual fish from other areas instead of increasing production. Monitoring of fishing activity and collection of other fishery information will greatly assist habitat managers in determining potential impacts on fish populations and will help fisheries resource managers to make decisions regarding the need for new regulations, changes in fishing practices, specific needs in public education, and the need for additional data.

In some cases, a socioeconomic assessment may be desirable to evaluate the impact of artificial fishery habitat improvements on a variety of social and economic factors within a given region of interest (e.g., state, county, municipal). Such an assessment may be considered important for measuring the overall success of an artificial habitat project or to provide information for cost/benefit analyses. Examples of factors that may be of interest include direct and indirect economic benefits, quality of fishing, fishing safety, fuel consumption per trip, and changes in fishing patterns or techniques.

#### 2.3.4.2 Maintenance

Maintenance also should be considered as part of any artificial habitat project. In some cases, maintenance may be necessary to comply with permit conditions (e.g., placement of buoys, materials scattering). Additional maintenance may be needed to enhance or maintain the effectiveness of the artificial habitat (e.g., adding or replacing materials). Some examples of typical maintenance requirements might include:

- Maintaining buoy systems to comply with USCG permit requirements,
- Periodically deploying new structures or replacing existing structures with materials more suited to the site conditions,
- Maintaining development and monitoring records for the project, and
- Updating information databases to be used for analyses.

### *2.3.5 Advantages and Limitations*

While the concept of constructing artificial habitat is relatively simple, it may be difficult to construct habitat that will directly target the species affected by CWIS operations. Nevertheless, several aspects of artificial habitats may make them useful for mitigating such impacts. A comparison of various types of materials and structures for artificial habitats, including advantages and disadvantages, has been compiled by the Gulf States Marine Fisheries Commission (1997). Some advantages and limitations of the use of artificial habitat are provided in Table 2-5. Another limitation regarding artificial habitats is that the actual habitat productivity is difficult to predict. For example, the presence of high fish densities on an artificial reef does not guarantee that the reef has increased net productivity of fish or that the fish on the reef were produced there (Ambrose and Swarbrick 1989). In contrast, a breakwater at King Harbor in California was found to be a functioning reef producing larval reef fish (Stephens and Pondella 2002).

**Table 2-5**
**Advantages and Limitations of Artificial Habitats as a Mitigation Tool for CWIS Operations.**

| Advantages | Limitations |
|---|---|
| Considerable amount of literature is available to assist with planning, design, deployment, monitoring, and maintenance of artificial habitats.<br><br>Well-developed body of scientific information exists about ecological effects and the types of fish species attracted to some types of structures.<br><br>Monitoring techniques have been developed.<br><br>Commercial vendors and experienced contractors are available.<br><br>May provide recreational opportunities for anglers and divers.<br><br>Fish often attracted shortly after construction of artificial habitat, resulting in immediate benefits.<br><br>Can often target specific life stages by altering the type of habitat being provided. | Better information needed to resolve issue about production vs. attraction of various fish species.<br><br>May not be feasible to directly target impinged or entrained species, although indirect benefits may result.<br><br>Some fish species may be prone to overfishing because of concentration around artificial habitats and the ease with which anglers can locate the area.<br><br>Although initial colonization is often rapid, it may take 10-20 years for a climax community to become established.<br><br>Monitoring costs may be high until it can be demonstrated that natural communities have developed and targeted ecological function has been restored or reached.<br><br>Some elements may need to be periodically replaced. |

### *2.3.6 Summary*

The construction of artificial habitat may be a viable means of compensating for fish resources affected by CWIS operations. Compared with major upgrades to CWIS structures, artificial habitat construction would also be cost-effective, depending upon the location for the project, how large an area would need to be developed, and the type of habitat being considered. Although reasonable predictions can be made in some cases about the types and life stages of fish that are likely to be supported by a particular project, it may be difficult to predict the numbers of those species or life stages that are likely to be supported or produced. However, the large amount of scientific literature available about the use of artificial habitats and ongoing research in this area will likely continue to improve the ability to develop artificial habitats to successfully accomplish specific mitigation goals.

## 2.4 Restoration of Fish Passage

The construction of hydroelectric and irrigation dams, flood control structures, and culverts has greatly affected the ability of migratory fishes to access riverine habitats. Dams and flood control structures (dikes and levees) are physical barriers that directly block fish movements upstream, downstream, or into off-channel habitats. Flood control structures can dramatically reduce both the access to, and availability of, off-channel spawning, nursery, and foraging habitats to riverine fishes throughout North America (Funk and Robinson 1974, Heinz Center 2002). Culverts may act as barriers to fish movement by either creating impassable high-velocity chutes within the culvert proper, or by cutting away the stream bed immediately below the culvert and creating a waterfall (Bates 1999). Blockage of migration routes can severely impede successful reproduction and lead to reduced populations or, in a worst case scenario, complete loss of a species from a particular aquatic ecosystem.

Diadromous is a general category describing fish that spend portions of their life cycles partially in fresh water and partially in salt water. This general category includes both anadromous and catadromous fish. Anadromous fish, such as Atlantic salmon, blueback herring, alewife, and striped bass, live as adults in marine habitats and migrate into freshwater to spawn. Catadromous fish, such as the American eel, live as adults in freshwater or estuarine habitats and migrate to saltwater to spawn. The construction of dams for hydropower production, flood control, and water supply have adversely affected the life cycles of many such species by limiting their movements between fresh and salt water spawning and nursery habitats (USACE 2002a).

Many freshwater species may also exhibit reproductive migrations between freshwater habitats of a particular watershed as part of their life cycles. For example, the federally endangered Colorado pike minnow is known to migrate 100 miles or more within the Colorado River Basin in western North America to reach specific spawning areas (Muth et al. 2000). Other migratory species, such as the federally endangered razorback sucker, require access by larvae drifting downstream in the riverine main channel to seasonally available off-channel nursery areas, such as flooded bottomlands and backwaters (Muth et al. 2000).

The restoration of fish passage, whether by providing upstream and downstream passage around obstacles or by removal of the obstacles can have a variety of ecological and environmental benefits (American Rivers et al. 1999, Chesapeake Bay Program 2002a, Heinz Center 2002). Benefits of providing upstream passage around obstacles are primarily associated with restored access by fish to historically utilized habitats (including spawning grounds and nursery areas). Benefits from downstream passage restoration are associated with the movement of larval and juvenile fish necessary to complete species-specific life cycles. Benefits associated with the removal of fish passage obstacles include not only those benefits associated with upstream and downstream fish passage, but also may include restoration of natural stream flows, temporal temperature and oxygen patterns, sediment and nutrient transport, and fish and wildlife habitat (American Rivers et al. 1999).

### *2.4.1 State of the Science—Fish Passage Techniques*

The restoration of fish passage has been widely used as an approach for mitigating the impacts of migratory obstacles on the distribution, abundance, and survival of freshwater and marine fishes. Restoration activities have addressed the restoration of both upstream and downstream movements of fishes, as well as movements between main channel and off-channel habitats (Muth et al. 2000).

**_Text Box 2-1. Common Fish Passage Techniques_**

- *Fishways*
- *Fish locks and lifts*
- *Transportation*
- *Dam removal or breaching*
- *Physical barriers and bypass systems*

The most widely used techniques for restoring fish passage can be considered as either active or passive in nature, both of which require careful ecological evaluation and engineering design. Active techniques involve the capture and transport of fishes around instream obstacles. Examples include fish lifts, fish locks, and transportation (Sale et al. 1991, Francfort et al. 1994, OTA 1995, Odeh 1999). In contrast, passive techniques do not involve the active capture of fishes. Rather, the fish themselves are responsible for movement around the obstacle. Examples of passive techniques include fishways (e.g., fish ladders), dam removal, and bypasses (Sale et al. 1991, Francfort et al. 1994, Amaral et al. 1998, Odeh 1999, USACE 2002c). The following section briefly describe the major types of fish passage techniques in use today.

#### 2.4.1.1 Upstream Passage Techniques

Upstream passage techniques focus on restoring the upstream migration of migratory species past riverine obstructions such as dams and roadway crossings. These techniques include fishways, fish lifts, fish locks, dam removal or breaching, and transportation.

***Fishways.*** Fishways provide fish an avenue past stream obstructions that would otherwise impede upstream migrations (Sale et al. 1991, Francfort et al. 1994, OTA 1995, Odeh 1999). Fishways typically consist of some sort of engineered flume or channel with internal baffles, stepped pools, or other mechanisms that are intended to slow water velocity to a level more easily traversed by fish (Flosi et al. 1998). All are intended to provide optimal water velocity and water depth to enable migratory fish to pass the obstruction. A variety of fishways are commonly used to restore upstream migration.

*Denil Fishway*. This type of fishway, conceptually designed in the early 1900s (Odeh 1999), is among the most common fishway design currently in use. It consists of a series of sloped channels or chutes with baffles inserted within the channels at an angle directed into the direction of water flow. The baffles produce areas of slower water flow that serve as resting places for migrating fish. Operable slopes range up to about 25% (OTA 1995). Flow through the Denil fishway is very turbulent. As a consequence, fish must swim constantly in the chute, and resting pools for fish must be included at certain intervals between individual channels or chutes so that fish can traverse the entire passage (OTA 1995, Kamula 2001).

*Steeppass Fishway*. A The steeppass fishway is similar to a Denil, except that it usually has only a single straight channel or chute with baffles along the sides and bottom that create turbulence to lower water velocity (Kamula 2001). Easy to design and install, it is relatively inexpensive (Maloney et al. 2000) and often prefabricated (OTA 1995). This type of fishway is typically used for relatively small obstructions and does not require resting pools. The Steeppass fishway is more efficient at controlling water velocity than the Denil fishway and can be used in steeper slopes (up to about 33%) [OTA 1995]). The steeppass fishway is often used in remote locations because it can be prefabricated in sections, is easily transported, and can be easily installed on location (Odeh 1999).

*Pool-and-Weir Fishway.* The pool-and-weir fishway consists of a series of individual pools arranged in a step-like formation ascending the obstruction. The pools are separated by walls or weirs that may or may not include openings or short chutes (Kamula 2001). Fish move from pool to pool by jumping or swimming over the weirs or by passing through the openings or chutes. Fish rest in the pools formed by the walls (Maloney et al. 2000).

*Vertical Slot Fishway.* The vertical slot fishway is similar to the pool-and-weir fishway because it also consists of a series of pools. However, the vertical slot fishway is designed with two baffles placed at the entrance of each pool to form a narrow vertical slot the height of the baffle for fish to pass through (rather than having to jump from one level to the next). These slots serve to concentrate water flow leaving the pool through the slots, while providing calm water within each pool to allow fish to rest (Odeh 1999). Fish may pass from pool to pool at whatever slot depth they select. Flow patterns within the pools and water velocities through the slots are largely independent on the water depth in the fishway (Kamula 2001).

*Culvert Fishway.* The culvert fishway is used to provide access for fish past obstructions associated with roadway stream crossings (Odeh 1999). This fishway is basically a pipe culvert with internal baffles of various shapes and sizes that reduce water velocities to passable levels (Clay 1995, Bates 1999, Odeh 1999). The design of the culvert fishway creates hydraulic conditions through the culvert that accommodate the swimming ability and timing of target species and sizes of fish. Culvert fishways follow three different designs (NMFS 2001). Active channel designs size a culvert sufficiently large and embedded deep enough into the channel to allow for the natural movement of bedload and formation of a stable bed inside the culvert. Stream simulation designs are intended to mimic natural stream processes within the culvert, with fish passage, sediment transport, and flood and debris conveyance intended to function as they would in a natural channel. Hydraulic designs match the hydraulic performance of a culvert with the swimming abilities of a target species and age class of fish.

*Eel Fishway.* Eels are catadromous fish whose juveniles (elvers) migrate upstream from the ocean to their freshwater habitats. Because of their snake-like shape, elvers can slither along a stream bottom under very low water depth and flow conditions. To take advantage of this locomotor style, eel fishways have bristles installed along the bottom. Only a small amount of water is needed at the upstream end of the fishway to allow elvers to slither between the bristles up to the top of the fishway (Odeh 1999).

***Fish Locks.*** Fish locks move fish over obstacles in the same manner they are used to move ships past dams. Fish enter the lock on the tailwater side of the dam, a downstream gate closes and an upstream gate opens allowing water to enter the lock. Once the water level reaches the forebay elevation the fish exit the lock above the dam (Clay 1995; Odeh 1999). An attractant flow may be needed to attract fish into the lock.

***Fish Lifts.*** Fish lifts (or elevators) are typically used only at very large obstructions, such as high head dams (Odeh 1999). An attractant flow of water is provided to guide fish into a large hopper at the base of the dam. The hopper then raises the fish to the top of the dam. The fish can then either be released into the river or transferred into holding tanks for transport to another tributary for stocking.

***Dam Removal or Breaching.*** Dam removal has received considerable attention in recent years as an approach to restore fish passage (both upstream and downstream) (Heinz Center 2002). As implied by the name, dam removal involves the complete removal of the dam to restore natural flow conditions (ASCE 1997, Odeh 1999, American Rivers et al. 1999, Baish et al. 2002). Low-level dams may be breached or notched to allow for fish passage. Breaching may also include the use of weirs below the breach or notch to reduce water velocities to levels that allow fish to move through the passage over a wide range of river flows (Odeh et al. 1995, Chesapeake Bay Program 2002b).

***Transportation.*** Transportation (sometimes referred to as ‘trap and truck’) is a fish passage technique that uses fish lifts to capture migratory fish in hoppers. Rather than transporting the fish over the top of the obstruction and releasing them into the river, the captured fish are placed into holding tanks and transported by truck, barge, or other method farther upstream for stocking (Odeh 1999). In the case of long reservoirs behind the migratory obstacles, this technique can be used to place migrating adults closer to the spawning grounds, thereby reducing migration delay (OTA 1995).

#### 2.4.1.2 Downstream Passage Techniques

Just as upstream passage allows fish to complete portions of their life cycles, there is a similar need to have adequate downstream passage. Downstream passage techniques focus in large part on directing downstream migrating fish toward some sort of conveyance mechanism that transports them a short distance to a trap-and-truck facility or to a plunge pool in the dam tailrace (Amaral et al. 1998).

***Transportation.*** As with upstream fish passage, transportation can be used to provide downstream passage of fish around dams. This fish passage technique uses physical diversions or bypass systems to direct fish into a collection area. The fish are then captured and loaded onto trucks or barges for transportation to release sites downstream of the dam (OTA 1995, Amaral et al. 1998, Giorgi et al. 2002, USACE 2002c).

***Physical Barrier and Bypass Systems.*** Physical barrier and bypass systems represent structural devices (such as traveling screens and bar racks) that physically exclude fish from entrainment at turbines and water intake structures and direct fish into a bypass system (OTA 1995, Amaral et al. 1998, 1999, Hanson 1999, Larinier and Travade 1999, Odeh 1999, Peven and Mosey 1999). The bypass system may transport the fish into a canal that rejoins the main channel below the obstruction, release the fish into the main channel via an outfall pipe or sluiceway, or transport the fish to a holding facility for later transportation (OTA 1995, Amaral et al. 1998, Odeh 1999, USACE 2002b).

### 2.4.2 Current Status

Fish passage mitigation is widely used to enhance fish migration and restore fish populations impacted by anthropogenic activities. There are about 76,000 dams greater than 6 feet high in the United States that act as barriers to fish passage (Heinz Center 2002). Fish passage restoration is currently being conducted in virtually every state by a variety of local, state, and federal agencies, as well as by the private sector and multiagency organizations (Sale et al. 1991, American Rivers et al. 1999, Heinz Center 2002). Numerous federal agencies, including the U.S. Department of Energy (USDOE), Reclamation, USACE, and USFWS, as well as private organizations such as EPRI, have all supported research on fish passage technologies and continue to do so (OTA 1995, Amaral et al. 1998, USACE 2002d).

The USFWS has established a National Fish Passage Program that works with state, local, and private sector partners to remove barriers and build structures to improve fish passage (USFWS 2002a). The program, which provides funding and technical assistance, focuses primarily on the reconnection of aquatic habitats for native fish and other species, especially species that are endangered, threatened, or migratory. Fish passage restoration projects completed through the National Fish Passage Program have provided fish access to more than 2,300 miles of river habitat and 24,000 acres of wetlands, and have been used to assist in the recovery of 50 endangered and threatened species (USFWS 2002e). Examples of projects under this program include culvert renovations to restore river access for salmonids in Washington (USFWS 2002f) and for the threatened leopard darter in Oklahoma (USFWS 2002g); dam removals in Maine for anadromous species including the American shad (USFWS 2002h) and in North Carolina for anadromous fish including Atlantic and shortnose sturgeon (USFWS 2002i); and dike removal to restore tidal flows and fish access to former salt marsh habitat (USFWS 2002j).

Fishways are being used to support recovery of endangered fishes in the Colorado River Basin. For example, a 350-foot fishway has been built at the Redlands Diversion Dam on the Gunnison River in Colorado to provide endangered (Colorado pikeminnow) and native fish access to 57 miles of historical habitat that have been inaccessible for nearly a century (USFWS 2002e). Since becoming operational in 1996, 51 Colorado pikeminnows and more than 35,000 other native fish have used the passageway. A fishway was constructed at the Grand Valley Irrigation Company Diversion Dam on the Colorado River in 1998 (USFWS 2002k), and together with planned upstream and downstream fish passage structures at the Grand Valley Project Diversion Dam and the planned removal of the 10-foot-high Price-Stubb Dam, will restore fish passage to 55 miles of historically occupied habitat for the Colorado pikeminnow and other endangered and native fishes (USDOI 2002, USFWS 2002k).

Fish passage techniques are used at electric generating facilities throughout the United States (Sale et al. 1991, Francfort et al. 1994, OTA 1995, Whitney et al. 1997, Knotek et al. 1997, Amaral et al. 1998, NMFS 2000). For example, 173 of the hydroelectric facilities licensed by the Federal Energy Regulatory Commission (FERC) in 1994 had some form of upstream fish passage mitigation in place, while 237 had downstream mitigation measures (Francfort et al. 1994). At these facilities, fishways accounted for 65% of all upstream fish passage mitigation, while physical barriers (screens and bar racks) (68%) and bypasses (27%) represented the most common measures for downstream passage mitigation. The Salem Nuclear Generating Station, which withdraws water from the Delaware Estuary, has constructed and operates eight fish ladders under its Estuary Enhancement Program and is required by its New Jersey PDES permit to construct an additional two fish ladders to support upstream spawning migrations of river herring (PSE&G 1999, PSEG 2003, New Jersey Department of Environmental Protection 2002, undated).

Transportation has been used to move both upstream migrating adults and downstream migrating juvenile salmon in the Snake River, Columbia River, and other salmonid rivers in the western United States (OTA 1995, NMFS 2000, USACE 2002c). Transportation has also been used on a small scale for blueback herring and alewife in the Chesapeake Bay (Chesapeake Bay Program 1999).

As part of a mosquito abatement program for the Indian River Lagoon in east-central Florida, dikes were used to impound wetlands along the lagoon (Poulakis et al. 2002); these dikes prevented the movement of fishes between the wetlands and the lagoon. Culverts are now being used to restore fish access to wetlands isolated by the dikes. Poulakis et al. (2002) evaluated fish use in a wetland that had been isolated for more than 39 years. After four fish passage culverts were installed, there was an increase from 9 to 40 species within 15 weeks after restoration of fish access.

Fish passage techniques are one of the many tools used by major river and estuary restoration programs throughout the United States. The Chesapeake Bay Program has been employing a variety of fish passage approaches throughout the Chesapeake Bay watershed (Chesapeake Bay Program 2002a). To date, more than 1,000 miles of dammed tributary habitat in the bay have been reopened to migratory fish. Five types of fish passage techniques are used in the Chesapeake Bay watershed, Denil, steeppass, vertical slot, pool-and-weir, and fish lifts. Some obstructions are removed, notched, or breached.

The State of Pennsylvania removed more than 25 dams statewide between 1995 and 1999, restoring access to hundreds of miles of river habitat (PFBC undated). The Connecticut Department of Environmental Protection Fisheries Division is actively involved in the protection and enhancement of anadromous fish runs in the state. Division staff construct and operate fishways at state-owned dams and provide technical assistance for fishway construction at privately owned dams (CDEP 2002).

The Narragansett Bay Estuary Program is another example of a large restoration program that includes restoring anadromous fish populations. The program has developed a four-phase fisheries restoration plan for the Blackstone River in Rhode Island. The program includes the restoration of fish passage using Denil fish ladders to provide upstream passage over the first four dams of the lower Blackstone River (USEPA 2002b).

In the Susquehanna River, fish passage facilities installed since the mid-1990s at three hydropower facilities have made over 450 miles of the Susquehanna River mainstem and its tributaries accessible to migratory fishes. The fish passage facility at the Conowingo Dam on the Susquehanna River, in operation since 1991, consists of two fish lifts that trap migrating fish. The facilities are capable of handling 1.5 million American shad and 10 million herring. Between

***Text Box 2-2. Case Study—Little Falls Dam Fishway Project***

*The Little Falls Dam, built in 1959 on the Potomac River, prevented anadromous fish from moving upstream in spring to spawn, blocking access to 10 miles of fish spawning and nursery habitat. Although the dam included a vertical slot fishway when it was constructed, this fishway was ineffective because the design had placed the entrance too far downstream from the dam to attract migrating fish, and its maintenance needs were too high because of large amounts of debris carried by the river. Operation of the fishway ceased in 1964. An intergovernmental task group was established in 1992 to plan and obtain funding for a new fishway at the dam. The new fishway design developed for the dam uses three "W"-shaped labyrinth weirs within and below a 36-foot-wide, 4-foot-deep notch in the dam. The weirs reduce water velocity to levels that allow fish to use the fishway. The fishway was centered at an area where migratory fish congregated below the dam (Chesapeake Bay Program 2002b).*

1985 and 1998, more than 350,000 adult shad were transported over the dam, and annual return of shad has increased from fewer than 2,000 to more than 100,000 fish (MDNR 1999, Smith and Bleistine 2002, PFBC undated). More than 200,000 American shad were lifted at the two lifts at Conowingo Dam in 2001 (PFBC 2001).

Fish passage restoration and enhancement represents a major component of the management of hydropower generation in the Columbia River Basin (USACE 2002a). The USACE has adult fishways and juvenile fish bypass systems in place at its eight lower Columbia and Snake River dams (USACE 2002b,e). The Columbia River Fish Mitigation Project was initiated to find ways to improve these systems. Since the project was begun in 1988, many changes, such as improvements to attraction flows for the adult fish ladders and extended-length guidance screens for juvenile bypass systems, have been made, and many more are being studied and implemented. The USACE Anadromous Fish Evaluation Program, formerly known as the Fish Passage Development and Evaluation Program, consists of a set of Corps-funded evaluation and monitoring studies designed to provide better biological information and insights related to fish passage and survival at hydropower dams (USACE 2002d). These studies include such topics as effects of juvenile fish transportation, evaluation of fish guidance devices and surface collection, effects of gas supersaturation on fish, and adult fish passage at the dams.

### 2.4.3 Applicability for Mitigating CWIS Operational Impacts

Fish passage techniques may provide direct and/or indirect mitigation of fish losses from impingement and entrainment at CWISs. Depending on the species being impacted by the operation of a CWIS, fish passage approaches can be used to restore access of the affected species to currently unavailable (but historically accessible) spawning and nursery habitats. By providing fish passage past the obstacles, access to additional habitats is increased, and CWIS operational impacts could be offset by increased production of the target species in the previously inaccessible habitats. To directly address species-specific impingement and entrainment impacts, the underlying mitigation assumption is that the species impacted by CWIS operations are also those for which migrations to spawning or nursery habitats have been blocked.

The restoration of fish passage may also result in environmental benefits for nontarget fishes by providing a similar increase in access to previously inaccessible habitats. For example, the fishway at the Redlands Diversion on the Gunnison River was designed to provide passage around the dam to historic habitat for the endangered Colorado pikeminnow. While the target species has been shown to successfully use the fishway, an additional 35,000 other native fish have also used the fishway since its opening in 1996 to gain access to previously unavailable habitat (USFWS 2002k).

The applicability of fish passage restoration to mitigate operational CWIS impacts will also depend, in part, on the spatial relationship between the existing CWIS of concern and the location of existing impediments to fish passage. Opportunities to restore fish passage may not exist within the vicinity of the CWIS, or even within the same watershed. In these instances, environmental benefits of fish passage restoration would be incurred by fish populations other than those directly affected by impingement or entrainment at the CWIS. The life history of the species needs to be considered. Natal fidelity could restrict the applicability of fish ladders to the same watershed. If no natal fidelity occurs, then the fish passageway can be located anywhere within the distribution of the species.

### *2.4.4 Design, Construction, and Operational Considerations*

Fish passage technologies can be very effective in restoring fish passage. Failure to effectively support fish passage may be due to one or more of a variety of factors, such as:

1. Lack of attraction flow,
2. Poorly designed entranceways and exits,
3. Insufficient capacity to move fish,
4. Unsuitable hydraulic conditions within a fishway or bypass system,
5. Improper operation,
6. Handling and transportation stress, or
7. Inadequate maintenance.

***Design.*** Regardless of the technique employed, restoration of fish passage requires careful design and construction. For example, the installation of a prefabricated steeppass fishway would require a much lower level engineering design and construction than would be necessary for the complete or partial removal of an existing dam or for the construction of a fish lift at a large dam. Similarly, most fishways will require relatively minimal modification of the migration obstacle (e.g., a dam), while the addition of fish lifts or locks likely will require extensive structural modification for construction of the lift or lock facilities. Numerous federal and state agencies have developed very specific guidance for designing and implementing fish passage technologies (see Appendix A).

The basic design requirements of many fish passage techniques are well understood (OTA 1995, Clay 1995), and some techniques (such as pool-and-weir and Denil fishways) have been in use long enough that the design specifications are almost standard and lend themselves to prefabrication. Similarly, the responses of fishes to fish passageways have been long studied (e.g., Jones et al. 1974, Slatick 1975, Slatick and Basham 1985, Blackett 1987, Peake et al. 1997, Laine et al. 1998; Bunt et al. 1999). However, fish- and site-specific information is critical to developing successful fish passage systems. Design and siting of a fish passageway requires information on the following biological and physical parameters (Flosi et al.1998):

- Life history parameters of the fish species of interest, including information on the timing and magnitude of fish movements, body size, and swimming ability,
- Probable access routes to the obstacle, including location of areas where fish are known or expected to congregate below the obstruction,
- The extent of known or potential spawning and nursery habitat and potential level of fish production from both above and below the obstruction,
- The type and quantity of anticipated debris that could be transported into the fishway by water currents,
- The hydrograph of the water body of interest, including magnitude, extent, and likelihood of extreme minimum and maximum flows, and
- Locations of other barriers (especially upstream) that could be affecting fish movements.

Mallen-Cooper (1999) cited these same factors when identifying four steps important for developing fishways for nonsalmonid fishes in Australia: (1) identifying the species and life stages (and sizes that are migrating); (2) testing these fish in an experimental fishway; (3) designing and building the fishway; and (4) quantitatively assessing the fishways using relevant performance criteria. General design considerations are summarized in Table 2-6.

Careful consideration must be given to the entrance to a fishway or to a fish lift or lock; the entrance must be designed to not only attract fish but to also facilitate their movement into the fish passage (Bunt 2001). Depending on the width and depth of the water body, multiple entranceways may be necessary. Similar considerations of water depth, flow, and hydraulics must be made in the design of fishways and bypass systems, as well as during the design of fishway and bypass fish exits (OTA 1995, Clay 1995, Bates 1999, Larinier and Travade 1999, Pevan and Mosey 1999, NMFS 2001). The slope and length of the fishway must be carefully calculated and must take into account the swimming ability of the target fish species (Haro et al. 1999a). The angle and velocity of the attractant flow leaving the entrance at the base of the fishway also play critical roles in assisting fish to find and enter the fishway. The size of the target fish must also be considered (e.g., they must be able to pass through the slots in a vertical slot fishway).

The success of fish passage restoration activities may be enhanced when done in conjunction with fish stocking programs. For example, two fish ladders were opened in 1994 on the Lehigh River to open up the lower 23 miles of the river to migratory fish (Hendricks et al. 2002). Dams constructed in the 1820s had blocked runs of anadromous American shad to this portion of the

**Table 2-6**
**Design Considerations for Implementing Fish Passage Technologies.**

| Fish Passage Restoration Technique | Design Considerations |
|---|---|
| Fishways | Life history (including timing of the migration), behavior, and swimming ability of target species<br>Fish size and slot width<br>Hydrologic conditions above and below the migration obstacle<br>Fish entrance and exit location and type<br>Hydraulic conditions within the fishway<br>Resting pool volume, depth, and location<br>Head differential between pools<br>Fishway slope<br>Minimum flow requirements for fish passage<br>Need for attraction flows<br>Potential for debris blockage problems<br>Fish exclusion needs for control of unwanted species |
| Fish lifts and locks | Life history, behavior, and size of target species<br>Location of the fish entrance and exit<br>Auxiliary water requirements<br>Need for attraction flows<br>Lock water inflow rate<br>Fish exclusion needs (e.g., for control of unwanted species) |
| Dam removal or breaching | Downstream sediment transport<br>Potential for contaminated sediments<br>Dam debris disposal<br>Fish exclusion needs (e.g., for control of unwanted species) |
| Transportation | Fish holding and handling facility requirements<br>Transportation equipment needs (truck, barge, etc.)<br>Holding and loading criteria, such as maximum holding times and loading densities |
| Physical barriers and guidance devices | Flow approach<br>Protection and guidance devices<br>Conveyance mechanism<br>Debris blockage<br>Tailrace plunge pool location and depth<br>Bypass entrance flow hydraulics |

Sources:  OTA (1995), Clay (1995), Flosi et al. (1998), Bunt et al. (1999), Odeh (1999), Kamula (2001).

river. Hatchery-reared American shad larvae had been stocked in the river since 1985. Hatchery-origin individuals were found to comprise 73-98% of adult American shad collected upriver of the first dam (Hendricks et al. 2002).

***Construction.*** Construction requirements will be site-specific; they will be strongly dependent on the fish passage technique selected, location, surrounding topography of the proposed passage development, hydrologic conditions at the passage site, and access to the site. Many of these factors are the same as those for any type of construction project.

Among the various fishway types, steeppass and culvert fishways will have the simplest construction demands and requirements. On the other hand, the multilevel Denil and pool-and-weir fishways may require considerable construction activity, such as excavating facility foundations and stabilizing bank conditions. Construction of fishway entrances would require construction within the river channel proper, further increasing construction complexity. Installation of fish lifts or locks at dams would require extensive construction activity, as would dam removal or breaching.

Construction of a fishway may require a variety of environmental permits. The USACE regulates activities in “navigable waters” of the United States, thus a permit from the USACE may be necessary for construction of a fishway. Many states also regulate activities in wetlands, streams, rivers, and dams and may require permits for fishway construction and operation. For example, a fishway project in Connecticut may require a Dam Safety Permit, a Water Diversion Permit, a Stream Channel Encroachment Line Permit, and a Structure and Dredging Permit or Tidal Wetlands Permit (Maloney et al. 2000). Local government agencies, such as local conservation commissions, may also have permit requirements that could affect fishway implementation.

***Operation.*** Most fish passage approaches, once implemented, require continued maintenance for optimal operation and use by the target fishes. The extent of maintenance and repair needs will depend on the type of fishway, construction materials, and operational complexity. For example, pool-and-weir fishways require regular adjustments of upstream water controls to provide optimum water depth and velocity for fish passage (Flosi et al. 1998). Denil fishways readily capture waterborne debris such as leaves and branches and may require daily maintenance during fish migration season to prevent blockage of the fishway. Concrete fishways may not require much repair for 25 to 50 years (Maloney et al. 2000), after which substantial repair may be necessary. Aluminum passageways may be more durable, while wooden fishway components (such as baffles) may require repair every 10 years or less. While few operations activities may be necessary following dam removal to restore fish passage, the mechanical components of fish lifts and locks may require regular planned maintenance as well as replacement of worn parts and mechanisms.

### 2.4.5 Monitoring

The design of any monitoring program will depend on the stated goals of the activity of interest, the success criteria developed for the activity, and the data required to show success criteria attainment (Jones 1986, Hellawell 1991, Elzinga et al. 1998).

While currently no standardized protocols exist for conducting fish passage evaluations, a number of approaches are used to evaluate fish passage success. These approaches include upstream and downstream sampling (Oldani and Baigun 2002), mark-recapture surveys (Amaral et al. 1998, Bunt et al. 1999), hydro-acoustic methods (Iverson et al. 1999, Haro et al. 1999b, Ploskey and Carlson 1999, Steig and Adeniyi 1999, Oldani and Baigun 2002), radio-tagging (Bunt et al. 1999, Rivinoja et al. 2001, USACE 2002d), and passive integrated transponder (PIT) tags (USACE 2002d).

The S.O. Conte Anadromous Fish Research Center (http://www.lsc.usgs.gov/cafl/lsc-afl.htm) (which performs basic and applied research on fish migration and passage behavior and on the evaluation of passages to enhance upstream and downstream movement of anadromous and migratory species) is currently developing a generic manual for fish passage evaluation that will describe practical hydraulic and biological methods for fish passage evaluation. The Bioengineering Section of the American Fisheries Society has developed guidelines for the development, evaluation, and application of technologies that will facilitate fish passage and/or protection through the development of sound scientific evidence (AFS 2000).

The evaluation of fish passage success has received mixed attention. Sale et al. (1991) evaluated environmental mitigation at hydropower facilities throughout the United States. Among the 30 facilities providing responses, 57% had no monitoring in place to measure performance of their upstream passage mitigation. Those facilities with monitoring programs generally evaluated success on the basis of passage rates (such as fishway counts). Among 66 hydropower facilities with downstream passage facilities, Sale et al. (1991) found 79% had some type of performance monitoring. Of the 14 facilities with downstream passage monitoring, fish passage and fish mortality were most commonly evaluated.

Francfort et al. (1994) also evaluated fish passage mitigations at hydroelectric facilities and found that when present, monitoring measured mitigation benefits largely in terms of numbers of individual fish moved around the hydroelectric facilities, with little evaluation of benefits to fish populations as a whole. A survey of nonfederal hydropower facilities that included upstream or downstream fish passage mitigation found that performance monitoring and quantifiable performance criteria are typically lacking (Cada and Sale 1993).

Measurement of fish passage use (total numbers passed and passage rates) was the primary monitoring approach used by various jurisdictional agencies (e.g., states) to evaluate fish passage effectiveness in watersheds encompassed by the Chesapeake Bay Program (Chesapeake Bay Program 1999). Other monitoring approaches included surveys of species composition and abundance in upstream and downstream habitats and monitoring for out-migration of larvae and juveniles (Amaral et al. 1998).

Factors such as passage efficiency and rate, time of passage, survival rates, and other increases or decreases in populations have been suggested as more appropriate measures for evaluating mitigation success (Francfort et al. 1994). Monitoring of outgoing migrations can provide a direct measure of natural reproductive success in reopened habitats above the obstruction, while tracking numbers of returning adults can provide insight into overall population response (Giorgi et al. 2002). For example, monitoring of juvenile fish may be conducted to confirm spawning success of target species, to confirm survival of stocked juveniles, and to determine relative contributions of stocked and naturally spawned juveniles (Chesapeake Bay Program 1999). Success criteria should focus on an acceptable level of use of the fish passage technique by the target species (e.g., American shad at the Conowingo Dam) and also on a desired population level response, such as increases in reproduction and abundance, or in the establishment of a desired fish community.

### *2.4.6 Cost*

Costs for restoration of fish passage include those associated with construction (including demolition activities in the case of dam removal or breaching), operation, and monitoring. Additional costs may also be incurred for design and environmental evaluation studies (Sale et al. 1991, Francfort et al. 1994). Construction, operation, and monitoring costs for fish passage will be directly related to a variety of factors, including:

- The nature of the specific passage technique selected, including its operational requirements,
- The environmental setting of the obstacle addressed by the passage approach,
- Access and ownership issues related to the obstacle (e.g., private dam),
- The target species, and
- The success criteria and monitoring objectives.

Fishway construction costs are proportional to the height of the barrier, with costs increasing with increasing obstacle height. Steeppass fishways may cost $10,000 for every vertical foot, while Denil fishways cost about $20,000 for every vertical foot up to a height of 6 feet and $25,000 to $30,000 per vertical foot above 6 feet (Maloney et al. 2000). Construction cost of a nine-step steeppass fishway at a 26-foot-high dam was reported at $176,000 (in 1993 dollars), while construction costs for two 73-level pool-and-weir fishways at a 185-foot-high dam was estimated at $40 million (Francfort et al. 1994). Costs for a culvert bypass, which may have little or no annual operational requirements, would be minor compared with that for the construction and operation of a fish lift at a large dam. Janvrin (2002) reported that it would cost $4.5 million and $40 million to implement fish passage at Lock and Dams 3 and 19, respectively, on the Mississippi River; with annual maintenance costs of $5,000 for each dam.

Long-term costs will be associated with maintenance of locks, fences, gates, signs, and other facility-specific infrastructure, as well as with monitoring. Costs can be expected to be greater at remote locations than at sites with easy access for construction, operations, and monitoring. Higher costs can also be expected at locations with more physically complex or challenging hydrologic conditions. For example, costs can expected to be greater for constructing a fishway entrance in deep, fast-flowing waters than in more shallow and lower-velocity habitats. A small steeppass fishway at a small dam (6-foot height) adjacent to a paved roadway may be expected to be far less costly to install than would an eight-level Denil fishway at a 25-foot dam located in rugged terrain.

Sale et al. (1991) surveyed environmental mitigation projects associated with hydropower facilities in the United States and reported costs for construction, planning studies, operation and maintenance, and annual reporting to be directly related to hydropower generation capacity. Cost ranges, by category (capital, O&M, studies, and annual reporting), for upstream and downstream mitigations reported by Sale et al. (1991) are presented in Table 2-7.

Francfort et al. (1994) conducted a similar survey of hydropower facilities and also noted positive relationships between costs and generating capacity; cost ranges are presented in Table 2-8. Most of the upstream mitigation projects included in Table 2-8 employed fishways of one form or another. Reported costs for upstream transportation (for only a single facility) included $68,000 for capital costs, $24,000 for annual O&M activities, and $2,500 for annual reporting (Francfort et al. 1994). For two facilities employing fish lifts, capital costs were $1.3 million and $2.0 million, O&M costs were $6,000 and $24,000, and annual reporting costs were $12,000 and $14,000.

Downstream passage approaches reported by Francfort et al. (1994) included various types of barriers and bypass systems. Reported costs for these bypass systems ranged from $60,000 to $472,000 for construction, $12,000 to $112,000 for design and environmental studies, $3,000 to $5,000 for O&M, and $1,000 for reporting. Physical barrier costs ranged from as low as $500 to $2.5 million for construction, from $4,000 to $156,000 for design and environmental studies, from $500 to $105,000 for O&M, and from $300 to $52,000 for annual reporting.

**Table 2-7**
**Fish Passage Costs (in 1991 dollars) for Upstream and Downstream Fish Passage Mitigation for 34 Reporting Hydropower Facilities in the United States.**

| Cost Parameter | Reported Cost Range |
|---|---|
| Upstream passage | |
| Capital costs | $21,000–$37,000,000 |
| Design/environmental study costs | $2,700–$190,000 |
| Operation and maintenance costs | $1,000–$717,000 |
| Annual monitoring and reporting costs | $1,600–$154,000 |
| Downstream passage | |
| Capital costs | $416–$13,777,000 |
| Design/environmental study costs | $3,200–$7,292,000 |
| Operation and maintenance costs | $216–$98,500 |
| Annual monitoring and reporting costs | $0–$10,800 |

Source: Sale et al. (1991).

**Table 2-8**
**Fish Passage Costs (in 1993 dollars) for Upstream and Downstream Fish Passage Mitigation for 50 Reporting Hydropower Facilities in the United States.**

| Cost Parameter | Reported Cost Range |
|---|---|
| Upstream passage | |
| Capital costs | $1,000–$34,600,000 |
| Design/environmental study costs | $1,400–$310,000 |
| Operation and maintenance costs | $500–$717,000 |
| Annual reporting costs | $900–$265,000 |
| Downstream passage | |
| Capital costs | $500–$2,593,000 |
| Design/environmental study costs | $4,000–$156,000 |
| Operation and maintenance costs | $500–$105,000 |
| Annual reporting costs | $300–$52,000 |

Source: Francfort et al. (1994).

Construction of the fishway proposed for the Grand Valley Diversion Dam on the Gunnison River has been estimated to cost between $3,100,000 and $3,800,000, while annual operation and maintenance costs are estimated to be $15,000 to $25,000 per year (USDOI 2002). A juvenile fish bypass system was installed at the John Day Dam to increase survival rates of downstream migrant fish. The system was completed in 1987 at a cost of $23,000,000 (USACE 2002f).

Costs for removal or breaching of a dam will be strongly linked to the size (height and width) and type (earthen, concrete) of the dam to be removed. Removal costs may include not only costs associated with the physical removal and disposal of the dam and debris, but also those associated with the removal and disposal of the sediments that have accumulated on the upstream side of the dam. Major sediment control measures may also be required to prevent downstream transport of the accumulated sediments, adding further cost to the overall project. In some cases, these sediments may contain high levels of organic and inorganic chemicals that may require special handling and disposal as contaminated materials.

A notch fishway was constructed on the Potomac River at Little Falls Dam, Maryland, to restore access of migratory fish to 10 miles of historic spawning and nursery habitat. The notch fishway, which included 36-foot-wide and 4-foot-deep notch and three labyrinth weirs, was constructed at a cost of $2,000,000 (Coastal America 1999). Removal of a 3-foot-high, 40-foot-wide dam on Muddy Creek in Pennsylvania was reported to cost only $1,500, while removal of the 85-foot-high, 720-foot-wide Two Mile Dam on the Santa Fe River in New Mexico cost $3.2 million (American Rivers 2002). Table 2-9 summarizes costs for some dam removals conducted in the United States between 1990 and 1999.

### 2.4.7 Advantages and Limitations

Fish passage restoration has been shown to be very beneficial in the recovery of migratory fish stocks, and numerous opportunities exist for the application of this environmental enhancement approach. For example, more than 76,000 dams in the United States are 6 feet or more high (Heinz Center 2002), and each poses some level of impediment to fish movement at a local or regional scale. While many of these dams continue to have important roles in flood control, irrigation, and water supply, many others are obsolete, abandoned, or pose safety concerns (Heinz Center 2002).

**Table 2-9**
**Costs for Various Dam Removals in the United States, 1990–1999.**

| State | Number of Dams Removed | Range of Dam Heights (ft) | Range of Dam Widths (ft) | Range of Removal Costs |
|---|---|---|---|---|
| California | 4 | 7–10 | 57–400 | $29,000–$9,500,000 |
| Colorado | 1 | 56 | 200 | $1,500,000 |
| Connecticut | 7 | NA[a] | NA | $8,000,000 |
| Maine | 5 | 9–24 | 50 -917 | $13,000–$2,100,000 |
| Minnesota | 3 | 9–20 | 120–150 | $46,000–$208,000 |
| North Carolina | 2 | 7 | 135–260 | $64,000–$205,000 |
| New Mexico | 1 | 85 | 720 | $3,200,000 |
| Ohio | 1 | 8 | 100 | $10,000 |
| Oregon | 4 | 8–28 | 56–225 | $30,000–$1,200,000 |
| Pennsylvania | 12 | 3–13 | 10–383 | $1,500–$200,000 |
| Vermont | 1 | 19 | 90 | $550,000 |
| Washington | 1 | 32 | 240 | $52,000 |
| Wisconsin | 32 | 10–60 | 60–450 | $5,000–$600,000 |

[a] NA = not available

Source: American Rivers (2002).

*Evaluation Results*

Numerous advantages are associated with the use of fish passage restoration to mitigate CWIS operational impacts (Table 2-10). Depending on the type of restoration activity considered, advantages may include simple design and construction requirements, control of unwanted species, restoration of natural flow conditions, and effectiveness for strong- and weak-swimming fishes. In addition, the various methods for restoring fish passage have a wealth of supporting scientific knowledge (e.g., fisheries, aquatic ecology, hydrology, engineering) (see Section 2.4.1). Fish passage restoration programs can be designed to target species such as endangered (USFWS 2002a) or recreational fishes (USACE 2002b,e). Fish restoration programs may also be developed to restore access by the general fish community to historic habitat.

Limitations with fish passage approaches may include (depending on the specific approach) high costs for very large (tall) obstacles, continuous maintenance requirements, high water or flow requirements, and a potential for increased stress and injury of the fish (Table 2-10). In addition, opportunities for restoring fish passage may not be available in the immediate location or within the same watershed as the CWIS, and thus may not be able to target the species most impacted by CWIS operations.

While fish passage restoration may be beneficial in the recovery of migratory fish stocks or the restoration of fish community assemblages, its applicability for targeting species that are directly affected by CWIS operations must be carefully considered. Two factors are important in considering fish passage restoration as a suitable environmental enhancement approach for mitigating CWIS operational impacts. First, the species impacted by CWIS operations should be the species that would be directly or indirectly benefited by fish passage restoration. Second, the location of a proposed fish passage restoration should be such that any benefits would be realized by the species affected by CWIS operations. If both of these factors cannot be satisfied, then any benefits from the restoration of fish passage should be viewed as general benefits to overall fisheries resources.

### 2.4.8 Summary

The restoration of fish passage has a long history and extensive body of knowledge and research, and research continues throughout the world. In fact, the level of knowledge in this area is so large that it may be considered a distinct multidisciplinary branch of fisheries science. There is no single solution for restoring fish passage. Approaches include the installation of fishways, fish lifts, fish locks, transportation, and dam removal. Effective fish passage design for a specific site and target species will require a thorough understanding of both the biology and behavior of the target species, a detailed understanding of hydraulic conditions at the locations of the planned restoration, and careful engineering design. Technologies for fish passage are considered well developed and understood and have been successfully implemented at many locations. Fish passage failure tends to result from less-than-optimal design criteria based on physical, hydrologic, and behavioral information, or lack of adequate attention to operation and maintenance of facilities. Effective fish passage design for a specific site requires thorough understanding of site characteristics (including design and operational information in the case of hydropower dams or water diversions).

**Table 2-10**
**Advantages and Limitations of Fish Passage Restoration for Mitigating CWIS Operational Impacts.**

| Fish Passage Technique | Advantages | Limitations |
|---|---|---|
| Fishways | Relatively simple design<br>Relatively inexpensive<br>Relatively low maintenance and cost<br>Demonstrated effectiveness in restoring upstream and downstream fish passage | Must be designed to complement target species size and swimming capabilities<br>Long-term maintenance to prevent debris blockage<br>Not cost-effective for large (tall) obstacles<br>Number of fish accommodated/unit time limited by fishway dimensions<br>May allow passage of unwanted species |
| Fish locks and lifts | Well suited for weak-swimming fish<br>Can transport large numbers of fish/unit time<br>Can be used to provide fish for upstream stocking<br>Can control passage of unwanted species<br>More economical for high head sites | Fish may experience crowding during peak migratory period<br>Require adequate attraction flows<br>Mechanically complex, with potentially greater maintenance needs<br>Relatively high operation and maintenance costs<br>Fish may incur increased stress and mortality from transport and handling<br>Locks may require very large amounts of water<br>Potential for fallback through spillway after release above obstacle |
| Dam removal | Complete dam removal restores natural flow conditions<br>Provides fish passage restoration for all species<br>Little or no maintenance<br>Public safety hazards reduced or eliminated | Relatively high costs<br>Potential sediment transport and contamination issues |
| Transportation | May be less costly than other fish passage techniques<br>Can target specific species<br>Beneficial when long reservoirs are involved | Labor intensive<br>Fish may incur increased stress, injury, or mortality<br>Possible impaired homing<br>Possible delay in migration<br>Low capacity to move fish during peak migration |
| Physical barriers and guidance devices | Many technologies well understood<br>Effective for any species of the size and swimming ability targeted by the design | Design requires knowledge of site hydraulic characteristics and swimming ability and size of target fish<br>Fish may incur increased stress and mortality from transport and release |

## 2.5 Fish Stocking

### 2.5.1 State of the Science and Current Use

Fish stocking has been used as a means to enhance fish populations for well over 100 years. Hatcheries were originally operated to mitigate for loss of natural spawning habitat and had the goal of enhancing the harvest of adult fish for commercial fisheries (Flagg et al. 2000). Fish stocking is now conducted for a number of reasons, including supplementation, mitigation, restoration, preservation, and research. Environmental concerns also have become a focus of fish stocking programs. Fish stocking (including hatchery operations) may now be considered a distinct branch of fisheries science based on the level of knowledge and ongoing research on this topic.

**_Text Box 2-3. What Is Supplementation?_**

*Supplementation is the stocking of fish into natural habitats to increase the abundance of naturally reproducing fish populations (see Flagg et al. 2000).*

Fish stocking as an enhancement tool requires consideration of the season and locality of releases and the size and numbers of fishes to be released. These factors must be balanced against economic considerations, including the cost of hatchery operations compared with the economic benefits resulting from stocking (Travis et al. 1998). Conditions where stocking hatchery fish may be justified include (1) stocking waters that contain no fish; (2) stocking for “put and take” or “put, grow, and take” fisheries; (3) stocking to restore native species (including threatened or endangered species) that have declined; (4) stocking to introduce a new species or new genetic strain; (5) stocking for research purposes; (6) stocking predators to balance populations or for biological control; (7) stocking to offset fish kills caused by low oxygen levels or pollution; and (8) stocking to overcome habitat limitations (Heidinger 1993, Holt 1993, Tucker 1999, Wattendorf 2002). Stocking may be the only practical alternative where natural spawning has been disrupted, spawning grounds have been destroyed or have become inaccessible, exploitation is extensive, production is reduced, or a new species is desired (Sheehan and Rasmussen 1993).

Conservation hatcheries can play a major role in the recovery of threatened and endangered species, while production hatcheries are significant contributors to harvests for subsistence, recreational, commercial, and ceremonial fisheries (Hatchery Scientific Review Group 2000). State and private hatcheries have been successful in providing stocks of warm- and coldwater fishes for recreational and commercial uses. Some are also involved in the recovery of wild salmon runs. In contrast, the National Fish Hatchery System has the responsibility to conserve, restore, enhance, and manage the nation’s fishery resources and aquatic ecosystems. This responsibility includes the recovery of threatened and endangered species, restoration of native fish populations, mitigation for fishery losses from federal water projects, and providing fish stocks to benefit Tribes and National Wildlife Refuges (USFWS 2002b).

Stocking has been a major component of recovery programs for salmonids in the Northwest and the Great Lakes and for endangered species in the Colorado River Basin. Early recovery attempts for endangered Colorado River fish generally met with failure because stocking was conducted without any consideration of habitat restoration. For example, the lack of sufficient wetland areas and slow-moving backwaters may have decreased the ability of some stocked fishes to survive and reproduce (USFWS 2002a). Hatcheries used to help restore Colorado River species now work with the following guidelines: (1) raising fish whose behavior and genetic background closely match that of wild fish; (2) whenever possible, adult fish used as brood stock come directly from the wild; (3) a large number of adult fish are used to produce offspring in order to maintain genetic diversity of young; and (4) refuge ponds are used to maintain endangered fish as insurance against a catastrophic event (e.g., chemical spill) in the Colorado River (USFWS 2002a).

Stocking, in combination with reduced fishing mortality (e.g., moratoria or size limits), accelerated the recovery of striped bass stocks in the Chesapeake Bay (Richards and Rago 1999). Hatcheries and fish stocking are important components of Alaska's salmon enhancement program. About 1.4 billion salmon were released and nearly 40 million were harvested as a result of this program (McNair 2001).

Artificial propagation of fish species in the United State has become a major industry. For example, hatcheries provide more than 90% of the inland catch of resident salmonids, about 75% of all coho and chinook, and 88% of all steelhead harvested in Washington (Washington Department of Fish and Wildlife 1997). About 40% of all recreational fishing in Michigan depends on stocked fish, including 70% of Great Lakes salmonids (Michigan Department of Natural Resources 2002). Hatcheries can also have an important role in meeting Tribal treaty harvest obligations (Hatchery Scientific Review Group 2002). The United States currently has about 370 state-operated and more than 1,200 privately operated coldwater (e.g., salmon and trout) aquaculture facilities (Epifanio 2000). The National Fish Hatchery System consists of 70 hatcheries, 7 technology centers, and 9 fish health centers operated by the USFWS (USFWS 2002b). Table 2-11 summarizes the goals and highlights of several of the national fish hatcheries.

In the 1980s, the striped bass population in the Savannah River Estuary suffered a drastic decline because of high salinities. After the causes of the high salinities were corrected, the Georgia Department of Natural Resources in 1990 began a hatchery-based stock-enhancement program aimed at restoring a self-sustaining striped bass population in the Savannah River. Recovery of the striped bass population may already have begun, but it is still at an early stage. The time lag between stocking of juveniles and their maturation into large, highly fecund females could take 8 to 10 years (Will et al. 2002).

An experimental red drum (*Sciaenops ocellatus*) stock enhancement program was conducted in Port Royal Sound in South Carolina (Collins et al. 2002). Many of the stocked fish remained in the general area of release until reaching maturity. These results suggest that small areas containing appropriate habitat could be designated as marine reserves (i.e., no-take zones) in order to increase the success of the stocking program and thus enhance recruitment to the spawning stock of red drum (and possibly other estuarine species) (Collins et al. 2002). Studies have also shown that the release of hatchery-reared blue crab (*Callinectes sapidus*) juveniles has the potential to enhance local blue crab stocks when linked to other management approaches

**Table 2-11**
**Goals and Highlights of Select National Fish Hatcheries (NHFs).**

| Hatchery and Annual Operating Budget | Goals and Highlights |
|---|---|
| Bears Bluff NFH<br>Wadmalaw Island, SC<br>$213,600 (FY 01) | Restore and manage interjurisdictional coastal and riverine fishes such as shortnose and Atlantic sturgeon. Produced 116,000 endangered shortnose sturgeon fry in FY 99. No hatchery-produced sturgeon are used for restocking, although that is a probable long-term objective of the recovery effort. |
| Chattahoochee Forest NFH<br>Suches, GA<br>$363,400 (FY 01) | Annual production of about 120,000 pounds of rainbow trout that are stocked in public waters to compensate for federal water development projects in northern Georgia. Production from hatchery accounts for more than 360,000 angler days with an economic value of more than $30 million. |
| Dale Hollow NFH<br>Celina, TN<br>$563,819 (FY 01) | Annual production of more than 1.6 million rainbow trout, 210,000 brown trout, and 100,000 lake trout for stocking in Tennessee and Georgia as mitigation for water development projects (impoundments). |
| Natchitoches NFH<br>Natchitoches, LA<br>$450,000 (FY 01) | Annual production of between 500,000 and 750,000 striped fingerlings; spawn about 750,000 paddlefish fry annually; spawn and culture endangered pallid sturgeon; and provide largemouth bass, bluegill and catfish for recreational fishing. |
| Norfolk NFH<br>Mountain Home, AR<br>$640,700 (FY 00) | Annual production of 500,000 pounds of rainbow, cutthroat, and brown trout for statutory mitigation fish stocking for eastern Oklahoma and the White River Basin in northern Arkansas. |
| Private John Allen NFH<br>Tupelo, MS<br>$254,000 (FY 02) | Annual production of 250,000 Gulf Coast striped bass; 40,000 paddlefish; 150,000 walleye; and more than 500,000 largemouth bass, bluegill, redear sunfish and channel catfish. Also developing spawning and rearing techniques for sturgeon and alligator gar. |
| Wolf Creek NFH<br>Jamestown, KY<br>$296,900 (FY 01) | Annual stocking of 682,400 rainbow trout and 91,950 brown trout throughout Kentucky for federal mitigation waters and reimbursable agreements to meet management goals for state-controlled waters. The annual direct and indirect economic benefits of the stocking program are estimated at $50 million and more than $75 million, respectively. |

Source: USFWS (2002d).

(e.g., the development of protected migratory corridors that link juvenile release areas to spawning sanctuaries; Zohar et al. 2003).

The USFWS, Pennsylvania Fish and Boat Commission, New York Department of Environmental Conservation, and the Maryland Department of Natural Resources, in cooperation with several energy companies, have used fish stocking in conjunction with other methods (e.g., regulating harvest, improving degraded habitat, and constructing fish passage facilities) to restore shad to tributary streams (e.g., Susquehanna River) of the Chesapeake Bay (Native Fish Conservancy 2002). The actual stocking is done by a number of government agencies, nonprofit groups, schools, and Native Americans. By stocking young shad in upstream areas that have been inaccessible to migration for decades, adult fish would return to spawn in those areas when they are 4 to 5 years old (Alliance for the Chesapeake Bay 2000). These methods are showing positive results. It has been estimated that it will take 10 to 15 years to see recovery of the American shad in the James River with continued hatchery operations or 20 to 30 years to rebuild the population without further stocking (Alliance for the Chesapeake Bay 1994). The restoration program goal is to stock 20 to 25 million young shad annually in a number of tributaries of the Chesapeake Bay in Virginia, Maryland, and Pennsylvania. This goal has been exceeded in some years (e.g., 33 million in 1998, 27 million in 1999, 36 million in 2000, and 31 million in 2001) (Blankenship 1999, 2001, Alliance for the Chesapeake Bay 2000). Similar success is being realized from a combination of installed fish ladders and stocking in the Lehigh River, a tributary of the Delaware River (Hendricks et al. 2002). The goal is to build up shad populations to the point where natural reproduction from returning adults would replace the need for hatchery efforts (Blankenship 2001).

### *2.5.2 Applicability for Mitigating CWIS Operational Impacts*

The logic behind using fish stocking to mitigate CWIS impacts is that releasing a large number of larvae, juvenile, or adult fishes into a water body may directly compensate for the mortality associated with impingement and entrainment. Secor and Houde (1998) concluded that in years of poor natural recruitment, stocking post yolk-sac larvae into estuarine tributaries could supplement stocks of striped bass and possibly other anadromous species that experience high embryo and yolk-sac larvae mortality. This same principle could be applied to species that experience sufficiently high entrainment losses of eggs or larvae to prevent them from attaining their potential carrying capacity.

Ecological, economic, and political considerations must be taken into account when fish stocking is being considered to mitigate impingement and entrainment losses. A stocking program would benefit from the participation of fisheries managers, geneticists, fish culturists, bioengineers, water quality specialists, nutritionists, and ecologists (Stickney 1994). The participation of representatives from the energy company, regulatory agencies, and citizen and environmental groups would also be advantageous.

Various approaches can be used to determine the applicability of using fish stocking to mitigate CWIS impacts. For example, modeling can be used to determine population-level risks from impingement and entrainment and to determine stocking levels required to mitigate those CWIS impacts. Information would be needed on which species of fish should be stocked, what numbers and sizes should be stocked, and where and when the stocking should occur. For instance, the release of fish should be timed to balance the availability of appropriate food resources while minimizing predator pressures (Travis et al. 1998). The required information can be obtained from impingement and entrainment monitoring, creel surveys, and habitat mapping. Additional information will be needed on the survival and growth of stocked fish, their potential to disperse throughout the water body, habitat carrying capacity, and other items.

Determining the amount of stocking that would be required to compensate for CWIS losses is more easily accomplished if the same species that are impinged or entrained are also available for stocking. It is more difficult to estimate how much stocking would be needed to provide a particular level of compensation for fish species that are indirectly impacted by CWIS (e.g., fish that prey upon the impinged species). Section 4.4 provides a more detailed discussion on establishing fish stocking levels to compensate for CWIS impacts.

Hatchery management decisions must be made as part of a systemwide effort (Hatchery Scientific Review Group 2002). A number of the areawide recommendations made for the Puget Sound and Coastal Washington Hatchery Reform Project by the Hatchery Scientific Review Group (2002) are applicable to many regions and would be applicable to fish stocking as a means to mitigate system losses from impingement and entrainment. These recommendations include (1) a regional approach to managing hatchery programs, (2) operation of hatcheries within the context of their ecosystems, (3) measuring success in terms of contribution to harvest and conservation goals, (4) emphasizing quality over quantity of fish released, (5) incorporating flexibility into hatchery design and operation, (6) evaluating hatchery programs regularly, (7) using in-basin rearing and locally adapted broodstocks, (8) taking eggs over the natural period of adult return, (9) developing spawning protocols to maximize effective population size, and (10) considering both freshwater and marine carrying capacities in sizing hatchery programs.

Fish stocking can be used as the primary means to compensate for impingement and entrainment when the impacted species can be obtained from a hatchery or when suitable restoration sites are not available for enhancement (USEPA 2001a). In 1992, the San Onofre Nuclear Generating Station was required to contribute $1.2 million toward construction of an experimental fish hatchery and subsequent evaluation program for restoration of a white sea bass fishery.

A fishery enhancement program was used to mitigate entrainment losses from the Chalk Point Power Station. The fishery of the Patuxent River was being adversely impacted by entrainment of forage fish (bay anchovies). Entrainment decreased the annual production of bay anchovies by 10 to 20% which in turn was causing losses of game fish (especially striped bass) by 4 to 20%. This fish loss equated to an annual economic loss of $150,000 to $860,000. The enhancement program included stocking of striped bass and other species (e.g., American shad) designated by the Maryland Department of Natural Resources and the removal of obstructions to migratory fish (Bailey et al. 2000).

The striped bass stocking conducted by the energy company was part of a larger striped bass restoration program throughout the Chesapeake Bay. The energy company contributed more than 3 million of the 11 million striped bass that were stocked. The energy company's efforts contributed 30% of the striped bass spawning stock in the Patuxent River and 10% of the striped bass fishery in Chesapeake Bay near the Patuxent River. The energy company shifted its stocking efforts to American and hickory shads within the Patuxent and Choptank Rivers as part of a basinwide effort to restore shad to tributaries of Chesapeake Bay (Bailey et al. 2000, Willenborg 1999). In 2001, the energy company's aquaculture program produced more than 75,000 striped bass, 75,000 yellow perch, 230,000 American and hickory shad, and 19,000 largemouth bass (Mirant Corporation 2002).

At the Quad Cities Station, located on Pool 14 of the upper Mississippi River, walleye (*Stizostedion vitreum*) are reared in the retired spray cooling canal, and hybrid striped bass (*Morone saxatilis* x *M. chrysops*) are reared in the station's fish laboratory for release into the Mississippi River as part of the agreement to allow the station to operate in the open-cycle mode (LaJeone and Monzingo 2000). Recreational angling opportunities for both species have greatly improved in Pool 14 and several other navigation pools as a result of this commitment. Conservatively, the adult walleye population in Pool 14 consists of 30% stocked fish (LaJeone and Monzingo 2000).

### 2.5.3 Monitoring

Monitoring should be implemented to (1) determine that stocked fish survive, grow, and contribute to recruitment (i.e., measure stocking success); and (2) ensure that hatchery-raised fish do not displace the wild stock population (where this issue is of concern) (Leber et al. 1996). Periodic monitoring would identify whether changes were needed in the stocking program (e.g., stocking level and frequency, locations, and species or life-history stages). Long-term monitoring may be necessary to evaluate stocking success because of the uncertainty in predicting the success of artificial production and because future ecosystem conditions could change from either anthropogenic alterations or natural variation (ISAB 2000).

### 2.5.4 Cost

Hatchery construction, operation, and maintenance can be costly. For example, the annual operating costs for the fish culture program run by the New York State Department of Environmental Conservation is about $4.6 million for an annual production of about 1 million pounds of fish ($4.60/lb) (New York State Department of Environmental Conservation 2002). The proposed 2003 budget for the operations and maintenance of the National Fish Hatchery System is more than $55 million (USFWS 2002c). Using the National Fish Hatchery operation and maintenance cost averages, the estimated production cost per stocked fish (5 to 10 inches long) is $1.42 (1999 dollars) (USEPA 2001a). The USEPA (2001a) estimated that 25,000 to 100,000 fish per year (1 million per year for a worst-case scenario) would need to be stocked to compensate for cooling water intake losses, and that restocking would typically have to be done on a yearly basis. Therefore, the yearly costs could range upwards of $145,000 (cost of 100,000 fish and their transportation) (nearly $1.45 million for the worst-case scenario). However, these cost estimates are economically feasible compared with the cost of upgrades and annual operating and maintenance costs for intake screens or cooling towers (USEPA 2001a).

The annual cost of Wisconsin's contributions to salmonid stocking in the Great Lakes is about $2.5 million. However, this expense also includes other activities, such as assessment of the stocking program and stocking warmwater species into the lakes. This modest investment in stocking returns about $100 million in direct expenditures and a $200 million economic output (Bureau of Fisheries Management and Habitat Protection 1999). The cost/benefit ratio for producing fish at the major Florida freshwater hatchery is $4 to $6 for every dollar spent (Wattendorf 2002).

From the mid-1970s thru 1997, various energy companies invested more than $50 million for the American shad restoration in the Susquehanna River (for both hatchery operations and fish passage facilities) (Alliance for the Chesapeake 1997). However, successful enhancements can produce long-term economic benefits. Restoring recreational and commercial shad and river herring fisheries on the James River could be worth $5  to $7 million per year (Alliance for the Chesapeake 1997). However, until population restoration is complete, such economic benefits would not be realized. Investments to restore shad in Virginia has totaled about $13 to $15 per fish based on an estimate of 1 of 400 stocked fry surviving to returning as a spawning adult. Opening Virginia's rivers to fishing before the population is fully restored would put an end to stocking efforts, as spending $13 or more on a fish with a market value of $3 to $4 is not practical (Alliance for the Chesapeake 1998).

The total costs for rearing 7.8 million striped bass at U.S. federal hatcheries and power company hatcheries during the period 1985 thru 1995 were estimated at more than $7.1 million (more than $0.91 per fish) (Rufilson and Laney 1999).  Because costs of hatchery and stocking operations can be high, Rufilson and Laney (1999) suggest that surveys of juveniles and adults should be conducted to determine the most cost-effective release strategies, including age at release and optimal release conditions (e.g., salinity, temperature, and time of day for future potential stocking programs).

### 2.5.5  Advantages and Limitations

Relative to impingement and entrainment mitigation, one advantage of fish stocking is that it can be designated to specifically target those species impacted by CWIS operations. Hatchery operations could also be used to stock a species in peril for reasons other than impingement or entrainment. For example, Southern California Edison provided $4.7 million in funding for a white seabass hatchery to compensate for impingement and entrainment of other fish species at the San Onofre Nuclear Generating Station (Southern California Edison 2000).

Positive impacts associated with stocking can also include the increase of prey (e.g., the hatchery fish) for piscivorous species (Pearsons and Hopley 1999). Conservation hatcheries can be important for the recovery of a threatened

***Text Box 2-4. How Hatcheries Affect Natural Populations***

*Hatchery operations affect wild populations and their environment by:*

- *Physical structures,*
- *Ecological interactions, and*
- *Genetic mechanisms (Hatchery Scientific Review Group 2000).*

or endangered species by maintaining gene banks to avoid extinction, minimizing the risk of unpredictable environmental events, supplementing under-recruited wild populations that are below their natural carrying capacity, and introducing and maintaining naturally spawning stocks into barren habitats (Hatchery Scientific Review Group 2000).

In some situations, stocking can have both beneficial and adverse impacts. For example, salmonid stocking can create valuable recreational and commercial fisheries, but it also has the potential to replace indigenous species (Hilborn 1992, Joint Hatchery Review Committee 2001). It is necessary to balance the enhancement benefits of hatchery production against the potential ecological and/or genetic costs of stocked fish (Pearsons and Hopley 1999).

A central issue in stocking programs is whether hatchery fish enhance or replace natural production (see Secor and Houde 1998). Table 2-12 summarizes some of the beneficial and adverse effects associated with both fish stocking and the presence and operation of the hatchery itself.

Some negative results have been associated with stocking. Hatcheries have been identified as one of the factors responsible for the depletion of naturally spawning salmon stocks in areas such as the American Northwest (Hatchery Scientific Review Group 2002). Stocking may not only replace the native species being supplemented (e.g., genetic risks associated with interbreeding), but may also pose ecological risks to other species inhabiting the water body (e.g., by competition, displacement, predation, or pathogenic interactions) (Pearsons and Hopley 1999, Stickney 1994). Microbial infections (and other diseases) can sicken or kill fish in hatcheries, aquaculture pens, and captive broodstock, and, in turn, may impact wild stocks (NWFSC undated b).

The primary way to minimize the risks of stocking is to minimize interactions between hatchery and natural stocks. Three ways to reduce interactions are (1) reduce hatchery production, (2) minimize the straying of hatchery stocks to areas where natural populations are not influenced by hatchery production, and (3) minimize spawning of hatchery-reared fish that did not originate from the stocked water body (Joint Hatchery Review Committee 2001).

Captive rearing is one of the most promising means to preserve and restore depleted salmon stocks with minimal adverse impact on existing wild salmon (NWFSC undated a). However, many hatchery environments differ from “wild” environments relative to food, substrate, fish density, temperature, flow regimes, competitors, and predators (Waples 1999). Some of the differences between the hatchery and the “wild” environment can be ameliorated by designing new (or modifying existing) facilities to more closely mimic the environment that the stocked fish will encounter when released (Stickney 1994). The “hatchery” fish development cycle can also be drastically different than that for “wild” fish. For example, different hatcheries may be used for specific salmonid development stages (Iowa Department of Natural Resources 2002).

### *2.5.6 Summary*

Fish stocking can be used as a stand-alone, long-term enhancement method (e.g., if a site for habitat restoration is not available) (USEPA 2001a). Where use of stocking is the key component

**Table 2-12**
**Advantages and Limitations Associated with Stocked Fish and Hatchery Presence and Operation.**

| | Limitations | |
|---|---|---|
| **Advantages** | **Fish Stocking** | **Hatchery Presence and Operation** |
| Higher egg-smolt survival | Lower smolt-adult survival | Blockage to migration |
| Increase stock yield and rate of recovery | Inefficient foraging behavior | Water quality degradation |
| Conservation of rare and endangered species | Higher aggression and stress | Riparian loss and modification |
| Lower contaminant concentrations than wild individuals | Higher straying | Harassment from human presence |
| Nutrient enrichment (via salmon carcass supplementation) | Higher mortality | Instream flow modification |
| Commercial and recreational benefits (including the introduction of forage or trophy species) | Surface habitat preference | Impingement and entrainment |
| Ability to stock specific species, life stages, and locations | Low predator avoidance conditioning | Exotic species introductions |
| Satisfy public and political pressures | Lower breeding success | |
| Mitigate existing conditions such as habitat limitations | Less variable and duller coloration | |
| Redistribute fishing pressure | Genetic interactions with native/wild fish | |
| | Predation and competition | |
| | Disease transmission (to fish and amphibians) | |
| | Nutrient deficiencies | |
| | Ecological function (e.g., lower diversity and productivity) | |

Sources: Edwards et al. (2000), Felton et al. (1994), Flagg et al. (2000), Fleming and Gross (1992), Heidinger 1993, Kiesecker et al. 2001, Olla et al. (1998), Phillippart (1995), Polovina (1991), Hatchery Scientific Review Group (2000, 2002), Stafford and Haines (1997), Zabel and Williams (2002).

of a fisheries management program, funding from an energy company could be applied to those efforts (e.g., as was done by the San Onofre Nuclear Generating Station). Fish stocking can also be a component of an adaptive management plan that draws upon a number of enhancement approaches, such as restoration of fish passage or wetland creation. Adaptive management can be defined as systematic acquisition and application of reliable information to improve management over time (Wilhere 2002). Where adaptive habitat enhancements are a viable option, fish stocking is applicable as an interim action. For instance, stocking could be conducted during the 3 to 15 years it could take to restore a wetland or the 1 to 5 years to complete an estuary/tidal river restoration project (USEPA 2001a). Fish stocking would also be a complementary action where fish passage is used as an enhancement method. For example, shad restoration efforts in the Susquehanna River required a combination of regulating harvest of adult fish, improving degraded habitats, constructing fish passage facilities, and restocking upstream of the former blockage (Native Fish Conservancy 2002). In summary, the environmental and economic advantages and limitations of fish stocking would need to be evaluated against other enhancement methods (including best technology available for CWISs) and fishery management goals before being implemented to mitigate impingement and entrainment impacts.

## 2.6 Habitat Protection

### *2.6.1 State of the Science and Current Use*

Human encroachment in the form of residential and commercial development threatens to destroy or degrade many natural areas that provide important habitat for a variety of species. In an attempt to preserve remaining natural areas and to maintain their integrity, conservation organizations; individuals; corporations; and local, state, and federal governments often turn to habitat protection measures. Habitat protection through outright land acquisition, by its very definition, describes the process through which land and water resources and the species living therein are protected and preserved from any future threat (Press et al. 1996). Currently, through the help of individuals and the private sector, conservation organizations such as The Nature Conservancy (http://www. nature.org) and the Conservation Fund (http://www.conservationfund.org) have assisted in preserving and protecting land in all 50 of the states (Conservation Fund 2001). Habitat protection may be a means to mitigate for damages caused to the environment by operations or construction. Several approaches and levels of habitat protection are available, depending on the situation.

Whether undertaken by a conservation organization or a private-sector party, the process of habitat protection follows a basic approach, with the complexity of the details depending on the specifics of the habitat protection goals and objectives. After a decision has been made that habitat protection is the proper approach, the first step is to identify what species, habitat type, or property is to be protected. Although property may be chosen on the basis of the flora and/or fauna associated with that habitat, such as threatened or endangered species, the selection of a particular property is often determined by the availability of purchasable natural lands. Once a property is determined to be of interest, it is necessary to outline what activities or actions relative to maintenance, monitoring, and/or restoration may be necessary. This information, along with identification of potential hazards (such as non-point-source pollution, borders shared with those who may disrupt or disregard preservation efforts, or any other factors that could impact the long-term success of the habitat protection effort) will help to support the decision to purchase the property of interest. In the event that several potential properties are identified, a decision must be made on which parcel (or combination of parcels) to purchase. Following the purchase of the habitat, any restoration, management, monitoring, and protection activities are then initiated.

Habitat protection has become the mission of many conservation organizations, for example, The Nature Conservancy, the World Wildlife Fund (http://www.wwf.org/), the Conservation Fund, and Ducks Unlimited (http://www.ducks.org/). Although many groups that specialize in habitat protection are of national or international scope, there are also numerous smaller groups whose efforts may be more regional or local. Examples of such smaller groups include the Everglades Trust (Florida) (http://www.saveoureverglades.org/index.html), Save the Dunes Council (Indiana) (http://www.savedunes.org/), Jefferson Land Trust (Washington) (http://www.saveland.org/), the Southern Appalachian Highlands Conservancy (North Carolina) (http://www.appalachian.org/), and the Wilderness Land Trust (Colorado) (http://www.wildernesslandtrust.org/). Regardless of their scope, these organizations operate by accepting donations of land, money, goods, and services from individuals and private-sector parties, with the monetary donations used for purchasing and managing natural areas (Table 2-13). Another sector that often protects habitat alone or by partnering with both national and local groups consists of government agencies. This group includes federal, state, and local governmental agencies, such as the U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and various state natural resource and conservation agencies, among others.

Regardless of the groups involved, two basic approaches are used in implementing habitat protection: (1) direct purchase and sole responsibility for management of habitat and (2) partnering with another organization to complete the task. The private-sector parties may be involved at several levels with a conservation organization to complete a habitat protection project. These levels include hiring the conservation organization to manage company-owned land for preservation, donating untargeted funds for general habitat protection use to conservation organizations, donating targeted funds while maintaining limited partnering with the conservation organization, and donating targeted funds while participating in active partnering. Several of these types of arrangements are summarized below.

***Habitat Protection without Partnering.*** When a single entity undertakes a habitat protection effort, it must purchase and protect habitat by itself. Although this approach provides the entity sole recognition for the action and may allow for more specific project direction, it also leaves them with the sole responsibility of negotiating land purchases, preserving the habitat, and maintaining of the property and its ecological resources.

***Partnering for Entity-Owned Land Management.*** Partnering is useful when a private-sector party owns a tract of land and wants assistance managing and monitoring it for habitat

**Table 2-13**
**Examples of Some of the Partnerships between Conservation Organizations and the Private Sector.**

| Conservation Group | Private-Sector Party | Partnering Activities |
|---|---|---|
| The Nature Conservancy | Cannon | $10.3 million over last 10 years in funds, equipment, and volunteer services |
| | General Motors | $10 million over 10 years ($5.8 million in cash and more than 140 trucks) and $10 million toward Brazilian rainforest purchase/restoration project |
| | Nature Valley | $500,000 since 1998 through highlighting The Nature Conservancy's work on boxes and products |
| | Second Nature Software | $2.3 million since 1993 through donation of all after-tax company profits. |
| | Southern Company | $2.6 million since 1996 |
| | MBNA | $5 million since 1995 through offering no-interest credit cards to members and paying TNC a royalty on each account |
| | Royal Caribbean/Celebrity Cruises | Marketing partners with The Nature Conservancy |
| | The Preservation Collection | Ties with nature designs, 2% of net sales to conservancy |
| National Fish and Wildlife Foundation | Exxon Mobil | $9.1 million to date for 158 conservation projects through *Save the Tiger fund* |
| | Pacific Gas and Electric Company (PG&E) | $500,000 over three years to form the *Nature Restoration Trust* |
| Ducks Unlimited (DU) | Advantage Camo | Proceeds from sales of goods with camouflage pattern, as well as cash and product donations |
| | ARE Truck Caps and Covers | Sell Ducks Unlimited licensed products and are official sponsors of Ducks Unlimited |
| | Budweiser | Official sponsorship, $5 million over 25 years through artist-of-the year competition. |
| | Chevrolet | Provides vehicles for Ducks Unlimited and sells Ducks Unlimited edition Chevy trucks |
| | Flambeau Products | Donates a percentage of proceeds from decoy sales |
| | Hancor, Inc. | Donates a percentage of proceeds from water gate and pipe sales |

**Table 2-13 (Cont.).**

| Conservation Group | Private-Sector Party | Partnering Activities |
|---|---|---|
| Ducks Unlimited (DU) (cont.) | Innotek | Donates dog training products for fundraising and proceeds from Ducks Unlimited labeled merchandise |
| | MBNA | Support through Ducks Unlimited credit cards, total of $40 million since 1986 |
| | Winchester Ammunition | Supplies all trap loads for Ducks Unlimited sporting events, as well as other support |
| The Conservation Fund | American Airlines, Aspen Skiing Company, The Black and Decker Company, Chevy Chase Bank, Florida Rock Industries, Inc., IBM, Pacific Gas & Electric, REI, The St. Joe Company, United Parcel Service, Wagner Forest Management, Ltd., and many more. | All corporate donations are of $1,000 or more annually |

Sources:

The Nature Conservancy (http://nature.org/aboutus/corporatepartnerships/index.html)
The Conservation Fund (http://www.conservationfund.org/?article=2374&back=true)
Ducks Unlimited (http://www.ducks.org/supportdu/official_partners.asp)

protection. The Nature Conservancy together with Baltimore Gas and Electric (BG&E), for example, combined forces to manage and monitor an endangered beetle species. A major portion (90%) of the population of that beetle occurs on BG&E property at its Calvert Cliffs nuclear plant (Sawhill 1996). In this situation, BG&E benefited not only from an association with the conservation group, but also from hiring a knowledgeable conservation organization to manage and monitor their property. This arrangement saves the company from hiring and training their own staff to do work that the conservation organization already has the experience and infrastructure for doing.

Another example is the partnering of North Carolina Power and The Nature Conservancy. In this situation, a 5-km-long right-of-way owned by the energy company is managed and maintained by The Nature Conservancy by using low growing native vegetation species rather then mowing and applying herbicides to maintain the right-of-way. Several rare plant species are thereby being preserved and protected from the traditional right-of-way management practices (Sawhill 1996). Although this arrangement provides further management and protection of company-owned land, it does not necessarily protect habitat that was in danger of being developed and does not necessarily mitigate for resources impacted by CWIS operations.

***Partnering – Monetary Donation Only.*** Of the various ways the private sector can partner, the most direct, least participation-intensive involvement in habitat protection is the direct donation of funds to a conservation organization committed to the preservation of natural lands. This approach is entirely "hands free" on the part of the funding donor, and because the funds are untargeted, the conservation organization receiving the funds may use them wherever they feel appropriate. An example of this is the donation of $7 million by Duke Energy North America (DENA) to protect and preserve the Elkhorn Slough watershed in Moss Landing, California. This donation to the Elkhorn Slough Foundation, as required for Section 316(b) compliance by the NPDES permit for the Moss Landing Power Plant, will be applied toward purchasing, protecting, and restoring the slough, as well as helping to fund a permanent endowment for stewardship. Another example of this type of partnering is the Great Lakes Fishery Trust, which helps to rehabilitate Great Lakes fish species, protect and enhance habitat of the Great Lakes fisheries, fund research projects that benefit Great Lakes resources, and acquire property for the aforementioned purposes (www.glft.org). This trust was created by a partnership of Consumers Energy, Detroit Edison, and several conservation organizations to address the issues of fish losses at the Ludington pumped storage project hydroelectric facility in Michigan. These kinds of monetary donations can be effective means of partnering because they assist the conservation organizations in successfully completing habitat protection and/or restoration projects that are already in progress or that have been planned.

***Partnering – Purchase and Protection.*** Alternatively, private-sector parties may be more interactive with the conservation organization of their choice by partnering toward the common goal of protecting a specific habitat type, property, or watershed. In this kind of partnership, not only does the conservation organization benefit from the assistance and funding from a corporate sponsor, but the private sector party itself also benefits from being directly associated with the project and sharing responsibility for monitoring and maintenance, tasks that otherwise would have to be executed alone. Another benefactor of these types of partnerships is the environment.

One benefit of this type of partnership is that habitat that would be too expensive and/or expansive for a single entity to acquire and manage can be purchased under the partnering agreement. Large parcels of land may sustain more biodiversity or contain more species of importance than smaller parcels can sustain and may, therefore, be overall better investments for the future of native habitat and biodiversity. The private-sector parties, through their partnership with the conservation organization, have direct input and are able to stipulate the use of funds and other resources donated, and may even be able to protect habitat within their own watershed. For example, New York State and The Nature Conservancy partnered to protect of 44,650 acres of forested lands in New York. In 2002, the state of New York contributed more than half of the $9.1 million needed to preserve the Tug Hill Plateau in Lewis County (The Nature Conservancy 2002). Without the partnering of the two entities, it is likely that neither would have been able to purchase the land on its own. Another example of partnering is The Nature Conservancy's project to acquire and preserve a 26,880-acre prairie in Oregon. The cost of the land was $11.7 million, but through the assistance of the Oregon Watershed Enhancement Board (OWEB), more than 450 individuals, and the Bonneville Power Administration (BPA), a total of $11 million was acquired to help obtain the property (The Nature Conservancy 2001). Although this kind of partnering is more participation intensive on the part of the private-sector party than donating funds alone, it ensures not only the protection of valued lands, but also ensures that the private-sector party is definitely and directly linked to the project.

As noted above, both the habitat and the private sector can benefit greatly through partnering to accomplish habitat protection. Partnerships today are even extending to projects outside of the United States. For example, partnering of energy companies through the United States Initiative on Joint Implementation has led to protection of rainforest in Belize (Sawhill 1996).

### 2.6.2 Applicability for Mitigating CWIS Operational Impacts

The objectives of habitat protection are to protect existing, functioning habitats, thereby preserving biodiversity and ensuring the survival and production of the species that live therein. Protecting habitat can have several direct and indirect applications toward mitigating the effects of CWISs, as discussed below.

***Direct.*** There is direct application to mitigation for CWIS impacts when the habitat being protected is in the same watershed and specifically benefits the same species being impacted by CWIS operations.

***Indirect, But Within the Same Watershed.*** This type of arrangement occurs when habitat within the same watershed as the CWIS is protected, but the protection effort does not directly target the specific species affected by CWIS operations.

***Indirect, Outside of the Watershed.*** This category involves arrangements whereby the protected habitat does not directly benefit affected species and is also completely outside of the affected watershed.

When possible, protecting habitat that has direct benefits on local, affected species would be most applicable to mitigating fish losses at CWISs because local fish species would be spared further losses by habitat destruction. Protecting habitat within the same watershed would also help to support other ecosystem functions. By protecting functioning wetlands, riparian systems, and other habitats that may positively affect local fish populations, a link may be established between fish losses incurred by CWIS operations and the protected habitat. Alternatively, habitat protection may target habitats outside the local area and thus have little or no effect on specific fish populations impacted by CWIS operations. While this form of habitat protection has no connection to mitigating fish losses, the maintenance of regional and national biodiversity through habitat preservation has become an important effort in recent times, and thus in some situations might be acceptable mitigation for fish losses at CWISs. The indirect nature of this alternative for mitigating for fish losses at CWISs, however, necessitates discussion between regulatory agencies and the appropriate stakeholders prior to action.

If a decision is reached among stakeholders and regulators that habitat protection is indeed appropriate for mitigating fish losses at CWISs, questions may arise as to how much land protection is actually appropriate. Often, by the very nature of this alternative, the amount of property purchased is determined by the acreage and/or funds available. However, in order to quantify the number of acres that might appropriately mitigate for fish losses, it may be fitting to consider using the methods of other alternatives. Methods for quantifying wetland creation and restoration, SAV, artificial habitat, fish passage restoration, and fish stocking technologies are discussed in Section 4.4. By employing the methods discussed therein, it may be determined if the acreage available is adequate for mitigating fish losses at CWISs.

### *2.6.3 Monitoring*

Although habitat that is protected through purchase may be considered pristine, monitoring will likely be required. Upon purchase, a general health assessment should be conducted to establish baseline conditions. Borders need to be defined and maintained to ensure safety from outside influences; biodiversity and general health need to be monitored for changes. If any negative changes are found through monitoring efforts, measures need to be taken to ensure that the quality of the habitat does not further deteriorate. Monitoring needs will vary by habitat type and may include monitoring water quality in aquatic systems, surveying vegetation in terrestrial habitats, or any combination of monitoring and survey programs that will provide an overall assessment of the health of the habitat. Alternatively, when the donation of funds to another agency is part of the habitat protection effort, a certain level of administrative monitoring may be necessary to ensure that the donated funds are appropriated in the way they were intended.

***Text Box 2-5. Examples of Monitoring Parameters***

- *Biodiversity*
- *Ecological Condition*
- *Contamination*
- *Border Integrity*
- *Invasive Species.*

### *2.6.4 Cost*

Costs of protecting habitat through purchase are generally quite straightforward and involve (1) land acquisition and (2) upkeep, including monitoring. Land prices will most likely be concurrent with existing fair market values and will vary depending on the type, quality, and location of the land of interest (Table 2-14). Additional costs incurred for monitoring and maintenance will also vary by property size and location.

As shown in Table 2-14, actual property costs incurred by a conservation organization may be less than fair market value due to seller incentives, land donation, or conservation easements. More examples of this may be seen in Table 2-15, which provides a breakdown of some recent land purchase costs by The Nature Conservancy.

**Table 2-14**
**The Conservation Fund's 2001 Land Purchase Costs, by Region.**

| Region | Acreage Purchased | Fair Market Value (FMV) | Actual Cost | Cost per Acre (FMV/Actual) |
|---|---|---|---|---|
| Northeast | 22,113 | $54.2 million | $34.7 million | $2,451 / $1,569 |
| Southeast | 131,866 | $178.3 million | $117.9 million | $1,352 / $894 |
| Midwest | 11,759 | $13.8 million | $12.9 million | $1,174 / $1,097 |
| Mountain West | 22,600 | $49.5 million | $34.7 million | $1,748 / $1,535 |
| West and Southwest | 124, 039 | $16.1 million | $15.0 million | $130 / $121 |
| Nationally | 303,500 | $294.9 million | $215.4 million | $972 / $710 |

Source: Conservation Fund (2001).

### *2.6.5 Advantages and Limitations*

In recent years, habitat protection has proven effective in preserving lands and native species across the United States, and indeed throughout the world (Sawhill 1996, Conservation Fund 2001). It has become easier for individuals and the private sector to become involved in habitat protection through partnering with conservation organizations. Habitat protection may be an applicable method for mitigating fish losses at CWISs, as it is a means of preserving not only habitat, but biodiversity as well.

Advantages of protecting habitat, especially if it is within the affected watershed, include protecting habitat of fish species that may be directly impacted by CWIS operations. When land is being protected, there is often no need to spend time and money in restoration procedures because at some level habitat function is already intact. Although protecting habitat within the affected watershed would be the most desirable approach, limitations such as the availability of purchasable habitat, the threat of pollution or other ecological hazards, and finding that the only habitat available within the watershed requires major restoration efforts, are all very real. Habitat protection has many advantages and limitations as a means of mitigating for CWIS impacts, and many of these advantages and limitations (see Table 2-16) depend on the level of involvement with a partnering agency.

### *2.6.6 Summary*

Land acquisition is a method frequently used to protect valuable habitat from future threats (Press et al. 1996). It has become the mission of several national, state, and local groups and organizations, many of which partner with individuals and the private sector through donations and services, to protect more habitat than one entity could provide alone. Many partnering habitat protection projects have been successfully carried out across the United States and continue to be completed both here and abroad. Effective habitat protection projects to mitigate for fish losses at CWISs would require agreement of regulation agencies and stakeholders as to the applicability of the alternative, and in many cases would likely require partnering of the private sector with a conservation organization.

**Table 2-15**
**Recent Projects Completed by The Nature Conservancy and Their Costs.**

| Organization/ Project Location | Habitat Type | Acreage | Purchase Costs | Cost to Conservancy Group | Other Contributors | Cost Per Acre (FMV / actual for Conservancy/ actual for partners) | Comments |
|---|---|---|---|---|---|---|---|
| McCarran Ranch, Nevada | 20 miles of river | 305 | $800,000 | $300,000 | $500,000 | $2,623 / $983 / $1,639 | Protect and restore wetlands and river's natural contours: $7 million; entire project may cost up to $30 million |
| White Lake Preserve, Louisiana | Freshwater marsh, donated by BP | 71,000 | $40,000,000 | - | land | $563 / - / land donation | Maintenance and upkeep funding provided by private sector group donating land; additional $1.25 million |
| Tug Hill Plateau, New York | Spruce and hard-wood forest lands | 44,650 | $9,100,000 | $4,500,000 | $4,600,000 | $204 / $101 / $103 | Additional funds provided by New York State |
| Portland, Oregon | Prairie | 26,880 | $11,700,000 | $6,500,000 | $5,000,000 | $435 / $241/ $186 | An additional $4.3 million in initial management costs brings project total to $16 million |
| Atlanta, Georgia | Pine woodlands, sandstone outcrop | 756 | $1,260,000 | $600,000 | $660,000[a] | $1,667 / $794 / $873 | The total price includes closing costs and stewardship endowment |
| Lake Superior, Michigan | Forested shoreline, river, waterfalls, glacial lakes | 6,275 | $12,500,000 | - | $12,500,000 | $2,072 / $40 / $1,992 | The Nature Conservancy brokered the deal for Michigan Resources Trust Fund and only paid $250,000 for interest charges |
| San Luis Valley, Colorado | Baca Ranch, sand dunes | 97,000 | $31,280,000 | $13,080,000 | $18,200,000[a] | $322 / $135 / $188 | Citizens of the Valley to raise funds for interest on a $7 million loan |

[a] More than one contributor.
Source: The Nature Conservancy (www.nature.org).

**Table 2-16**
**Advantages and Limitations of Habitat Protection and Partnering with Conservation Organizations as a Mitigation Tool for CWIS Operations.**

| Habitat Protection Techniques | Advantages | Limitations |
| --- | --- | --- |
| Habitat Protection, Overall | Well-established protection agencies are available for partnering activities.<br><br>Once protected, native habitat is no longer in danger of development or destruction.<br><br>When protecting, there is no need to attempt to restore ecological conditions, at some level they are already intact. | There may still be the threat of negative influences from bordering properties, such as pollution, invasive species, etc.<br><br>The habitat being protected may not be in the same watershed, let alone protecting the species affected by CWIS operations.<br><br>If protecting a habitat that is not in pristine condition but deemed to be of high importance, some level of restoration may be necessary to restore complete function.<br><br>Specific habitat acquisition may be limited by land availability. |
| Habitat Protection Without Partnering | Credit for the entire project is given to the entity protecting the habitat.<br><br>Protecting entity may be able to target more specific resources than if lobbying for their interests with a partner. | Private sector must do all land acquisition negotiations and must hire and/or train staff to monitor and maintain property.<br><br>Depending on availability, the habitat protected may not be in the same watershed, and may not target resources that would best mitigate for CWIS impacts. |
| Partnering through Monetary Donation | This is a fast and easy way to be involved in habitat protection.<br><br>The entity donating funds is able to have their name associated with habitat protection.<br><br>There is no need for in-house expertise. | Funds donated in this way will be appropriated according to the needs of the conservation organization. This does not ensure that habitat protected benefits resources that would best mitigate for CWIS impacts. |

**Table 2-16 (Cont.)**

| Habitat Protection Techniques | Advantages | Limitations |
|---|---|---|
| Partnering through Monetary Donation (cont.) | After a one-time donation of funds there is no further obligation to negotiate with land owners, monitor land, or undertake any other tasks associated with protecting habitat.<br><br>Partnering agency is relied upon for technical expertise and to conduct day-to-day operations at protection site.<br><br>Partnering allows for resources to be pooled and for larger, more expensive tracts to be protected than one agency could do on their own. | |
| Partnering for Habitat Protection | Partnering with a conservation organization allows for more direct input as to how and where the funds are to be spent. This may include protecting CWIS-affected fish and/or may allow for protection within the same watershed, depending on availability of lands.<br><br>Partnering conservation agency is relied upon for technical expertise and for conducting day-to-day operations at protection site.<br><br>Partnering allows for resources to be pooled and for larger, more expensive tracts to be protected than one agency could do by itself. | Depending on availability, the habitat protected may not be in the same watershed and may not benefit resources that would best mitigate for CWIS impacts.<br><br>This level of involvement will be greater on the part of the donating agency in the form of time, staff, and money. |

# 3
# TRADING STRATEGIES

Environmental trading occurs between two entities when one sells a credit for better-than-required environmental performance to the other entity that uses the credit in lieu of directly meeting its own environmental performance requirements. For wastewater discharges from point and nonpoint sources, this type of trading is known as effluent trading. The electric power industry has taken advantage of various types of air emissions trading during the past decades, but has not participated in water trading efforts to date. More recent trading information released by USEPA (described below) suggests that the agency is now more amenable to considering market-incentive mechanisms such as trading than it has been in the past. Thus, trading may represent a more viable option at this time.

This chapter describes some of the situations under which trading might be a feasible and cost-effective solution to meeting Section 316(b) requirements. These concepts are very new and have not yet been practiced. There may be numerous other forms in which trading can be practiced for Section 316(b) purposes. The intent of this chapter is not to promote any exact approach for trading but to stimulate discussion and exchange of ideas that will lead to a wider range of cost-effective solutions. As noted in Section 1.4, trading is closely related to the use of the other types of enhancements described in this report in that all are designed to use an external mechanism to offset an impact. Generally enhancements or trading will offer a more cost-effective solution than will installation of additional CWIS technologies.

The CWA does not specifically approve or prohibit effluent trading. Consequently, few trades of water-borne pollutants have been undertaken. In January 1996, USEPA released a policy statement endorsing effluent trading in watersheds, hoping to spur additional interest in the subject. The policy statement outlines USEPA's support for five types of effluent trading:

1. Point source/point source trading—trading of pollutant allowances between two or more industrial dischargers or publicly owned treatment works (POTWs),

2. Pretreatment trading—trading of pollutant allowances between indirect dischargers to a POTW,

3. Intraplant trading—trading among outfalls within a single facility,

4. Point source/nonpoint source trading—trading of pollutant allowances between an industrial discharger or a POTW and a nonpoint source of pollutants, and

5. Nonpoint source/nonpoint source trading—trading of pollutant allowances between two or more nonpoint sources of pollutants.

To supplement the policy statement, USEPA published a draft framework document that provides much more information on implementation of effluent trades (USEPA 1996).

Veil (1997, 1998) evaluated the opportunities for trading in the electric power industry and found that they were not great. The pollutants that would be most difficult and expensive for energy companies to treat (and thus good candidates for trades) are primarily toxic chemicals. Because toxics affect not only entire watersheds, but also the areas in the immediate vicinity of the discharge points, it may not be practical for one trading partner to operate with relaxed toxics limits (potential for violation of water quality standards) while the other partner removes more of the pollutant than required. In fact, nearly all of the early trading cases described by USEPA (1996) involved trades of nutrient pollutants and not of toxics.

USEPA recognized that trading has not flourished and in 2001 began placing greater emphasis on developing new trading policies. Early in 2002, USEPA circulated a new proposed water quality trading policy, and on May 15, 2002, the policy was formally printed in the *Federal Register* (67 FR 34709). The new proposed policy embraces trading as a viable mechanism for achieving water quality goals. The proposed policy acknowledges that trades other than the traditional nutrient trades can occur on a case-by-case basis if the regulatory agencies concur with the trades. Further, it does not limit water trades to effluents, but rather refers to water quality trades. This should provide additional opportunities for trading to the electric power industry.

As further evidence of the increased emphasis placed on trading by USEPA's Office of Water, the preamble of the April 9 proposed Section 316(b) regulations for existing power-producing facilities contains an extensive discussion devoted to the concept of using trading as a mechanism to achieve Section 316(b) compliance (pages 17170 - 17173). USEPA's concept of trading excess entrainment reductions between plants is a form of trading fish for fish. This concept is described in the following section.

## 3.1 Trading Fish for Fish

Although USEPA does not make trading a part of its April 9 proposed regulatory text, the agency describes how a fish-for-fish trading program might work in the supporting preamble discussion. USEPA notes that the costs to comply with the impingement reduction targets are probably lower than those for meeting the entrainment reduction targets. The higher costs associated with entrainment control suggest that trades of entrainment credits are more likely to take place than trades of impingement credits. Therefore, USEPA focuses its discussion primarily on entrainment trading.

The concept behind a fish-for-fish trade is that one existing power producer may decide to implement entrainment controls that provide a greater degree of entrainment reduction than required by its permit. That company would trade the excess entrainment reduction to a second power producer that elects to purchase the entrainment credit rather than directly meet its own entrainment reduction target. Although this sounds straightforward, trading participants must consider several important issues before engaging in such a trade.

The first issue is the spatial scale of the trade. To balance a loss of organisms due to a relaxed entrainment reduction target at one partner's facility by the excess entrainment reduction provided by the other partner's facility, the two trading facilities should be located in nearby or at least geographically similar locations. USEPA considers three different spatial scales: within the same water body, within the same watershed, or within other water bodies that share similar characteristics. As an example of the third case, a facility located on a mid-Atlantic estuary might be able to trade with another plant in a different mid-Atlantic estuary that entrains similar species, as long as the same species are widely distributed throughout both estuaries.

The second consideration is how to quantify the units and common currency of trading. In other words, how much of an excess in entrainment reduction is needed at one facility to balance a relaxation of entrainment at the trading partner's facility, and how do you measure that quantity. The commodity being traded is fish or early life stages of fish. USEPA describes three different types of accounting systems that consider species density, species counts, and total biomass.

Under the species density approach (USEPA's preferred approach), the trading partners would estimate the number of eggs, larvae, juveniles, and small fish for all fish and shellfish species that are entrained and divide by the flow rate to get entrainment per unit flow factors. These factors could then be used to ensure equivalence between trading partners. USEPA includes a detailed example of how the species density calculations would be used on page 17172 of its April 9 proposal. The mechanism that is ultimately used to determine the equivalence of the trade could be very labor-intensive. However, there may be alternative approaches using different, less-labor-intensive metrics that could be developed by agencies and trading partners.

## 3.2 Trading Pollutants for Fish

Now that USEPA has opened the door for discussion of trading in the Section 316(b) context, there may be opportunities to look beyond fish-for-fish trades. One other approach to trading is to trade a reduction in pollution loading for a relaxed entrainment or impingement allowance (i.e., a pollutants-for-fish trade). This concept is similar to the environmental enhancement concept. A company agrees to a pollution control project that will directly benefit the same or a nearby water body as part of a Section 316(b) program. Under the enhancements discussed in the previous chapters, companies either improve or create habitat or directly increase fish stocks through raising and stocking target species. A pollutants-for-fish trade, while similar in result, would function somewhat differently. Rather than constructing or improving habitat or stocking fish, the company would undertake a pollution reduction project that would benefit the water body. By improving the water quality in that water body, presumably the new conditions would allow for a healthier ecological situation and larger fish populations in that water body. The pollutants that are reduced could be associated with that company's own operations or, more likely, would be external.

One hypothetical example of an external pollutant reduction is a power plant situated on a river in the Appalachian region. The river is fed by many streams coming out of historically coal-mined areas. The water quality in these streams is very poor because of acid mine drainage such that the water quality in the river is also impaired, and riverine fish populations are small. The ecosystem around the plant's location would be better served by improving the water quality in the feeder streams than by installing additional CWIS controls. The plant could undertake a trade with the state acid mine drainage reclamation agency to pay for restoration of a number of acres of abandoned mine lands each year in exchange for receiving relaxed CWIS requirements. The improvement in water quality could result in fish populations several times larger than before restoration.

Although the example cited above applies to cooling water *intakes*, a real-life project is currently underway to look at possible trading opportunities between power plant thermal *discharges* and acid mine drainage. Allegheny Energy and EPRI are funding a study through West Virginia University that will quantify and compare the ecological benefits associated with a range of environmental activities in the Cheat River basin. The goal of the study is to identify those environmental activities that will yield the greatest result to an ecosystem for a given cost. This is precisely what trading can offer.

Other situations that might fit into a pollutants-for-fish trade include sites that have diminished water quality by virtue of:

- Inadequately controlled storm-water runoff,
- Infiltration to surface waters of contaminated groundwater,
- Release of pollutants from contaminated sediments, or
- Other releases from sources that might not be otherwise controlled under existing environmental authorities.

The same considerations that are important in fish-for-fish trades are also important in pollutant-for-fish trades. What is the appropriate spatial or geographic scale? Because the effect of pollutant reduction may expand productivity of a large area of aquatic habitat, it not so critical to have the site of pollutant reduction be located very close to the site of the power plant receiving relaxed CWIS requirements.

As discussed in the previous section, valuation of the quantities being traded and conversion of those valuations to a common currency are important considerations. In the context of a pollutant-for-fish trade, the trading partners and regulators will need to estimate, for example, how many pounds of pollutant A must be removed to correspond to a 10% relaxation of entrainment requirements. Measurement and verification of the pollutant removal is relatively easy, but determining a fair relationship between the pollutant reduction and the entrainment relaxation will involve negotiation between trading partners and regulators.

## 3.3 Other Trading Issues

Trading introduces additional issues that must be evaluated. First, why trade? This can be examined from a cost/benefit perspective. The benefit part is easy—by utilizing a trade, the company is able to put its limited resources to the best use. The cost part is more complicated. In this situation, the cost is not so much economic cost, but the loss of direct control for the partner purchasing the credits (the buyer). Instead of constructing new facilities or modifying operating conditions, the buyer relies on the party providing the excess allowance (the seller) to accomplish something. If the seller fails to do the activity that is the basis of the trade, the buyer will still experience some regulatory liability. This loss of control is important to many companies. When weighing the costs and benefits, the benefits may need to be quite substantial to justify the loss of control associated with the trade. This factor should not be considered as a weakness of trading but simply as a calculated risk that is inherent in any business transaction. Corporate willingness to take risks with innovative and cost-effective environmental protection varies widely among companies.

A trading program is likely to involve a great deal more administrative requirements and monitoring than would a straightforward technical solution. This is particularly true at this point in time because neither regulators nor companies have any experience with Section 316(b) trades. The first several Section 316(b) trades that take place will most likely be subject to a higher than normal degree of scrutiny. The time and money associated with these requirements would add to the effective cost of a trade.

The issue of how to assign responsibility for noncompliance is a significant issue for any trade, and it is not yet clearly resolved. Almost certainly, the buyer will maintain some or all of the responsibility for complying with its permitted targets and limits. The seller may be listed in the permit and have joint responsibility, or may not have any direct responsibility to the regulatory agency. In the latter case, a buyer would need to seek its own legal actions against a seller if the seller failed to comply with its trading commitments.

Another issue that bears discussion is how to determine the magnitude of the credit or allowance that a seller may trade. In a fish-for-fish trade, presumably the seller will have a permitted limit for percent reduction of entrainment or impingement. For entrainment, the limit (according to the proposed regulations) would fall somewhere between 60 and 90% reduction over baseline. Now assume that the seller's permit limit is 60% and it has installed technologies that allow it to achieve 85% removal. If the seller wants to maintain a 10% margin of safety above its limit (i.e., 70%), it can then trade the remaining 15% to a buyer. This is the simplest situation. More complicated situations could arise, however. Consider the situation where a plant utilizes enhancements as the major component of it Section 316(b) strategy to meet a target of 75% reduction of entrainment. The company reaches an agreement with the regulatory agency that restoration of 100 acres of wetlands will meet that target. If the company decides to restore 200 acres or 500 acres of wetlands instead of 100 acres, it may be able to claim an excess credit beyond the 75% target. Conceivably, the company could justify that it was achieving an effective reduction greater than 100% reduction (because it was restoring habitat that allowed for more organisms in the ecosystem than would have been there naturally) and could trade a large percentage to a buyer facility.

Another situation that could arise is a case where a plant already is using wet cooling towers. This effectively achieves greater than 90% reduction in entrainment (often greater than 95%) and probably some improvement in impingement as well. Although the cooling towers were installed prior to the effective date of the Section 316(b) rule, the company may be able to claim that the plant exceeds the entrainment and impingement targets that it would have been assigned if it had operated using once-through cooling, and therefore seeks to trade the excess between its hypothetical target (maximum of 90% entrainment reduction) and its actual 90+% reduction target.

These latter two examples illustrate some of the complicated circumstances that could be associated with proposed fish-for-fish trades. Other circumstances relating to pollutant-for-fish trades can be envisioned also. Before trades can be utilized, it will be necessary for regulatory agencies to agree that trading can be part of a Section 316(b) program and then adopt policies, guidance, or regulations that implement trading.

# 4
# IDENTIFICATION, SELECTION, AND SCALING OF ENVIRONMENTAL ENHANCEMENT PROJECTS

## 4.1 Introduction

In previous chapters, particularly Chapter 2, a variety of environmental enhancement strategies were presented that could be used to mitigate impingement and entrainment impacts of CWISs. While the science of environmental enhancement to mitigate these CWIS operational impacts is relatively new and undergoing rapid development, environmental enhancements can be feasible alternatives to changes in plant design or operations. Environmental enhancements have been widely used by numerous federal, state, and non-governmental organizations to restore or enhance natural resources in a variety of environmental and regulatory contexts (e.g., Superfund, natural areas management, habitat conservation). This chapter discusses issues, approaches, and methods for selecting and scaling enhancement projects to adequately mitigate for CWIS impacts while satisfying regulatory requirements and stakeholder concerns. Scaling refers to the process of determining, for a particular restoration action, the amount of the action required to compensate for the resource injury.

Selection of the type and size of an enhancement approach (or combination of approaches) to mitigate CWIS operational impacts must consider a number of factors, including (but not limited to):

- Nature of the CWIS impacts;
- Mitigation objectives (e.g., the target species or resources);
- Level of scientific understanding of how well a particular enhancement approach may meet the mitigation objectives;
- Possible technological and/or operational solutions;
- Technical and practical feasibility of the mitigation strategy; and
- Costs and benefits of the mitigation.

Interactions, discussions, and negotiations among the energy company and appropriate stakeholders may be needed to address each of these factors.

### *4.1.1 USEPA Section 316(b) Proposed Rule*

The USEPA is scheduled to finalize its proposed revision of the Section 316(b) regulation for existing CWISs withdrawing more than 50 MGD (i.e., Phase II Rule) by February 16, 2004. Under the proposed USEPA rule, a facility may choose one of three options for meeting "best technology available" (BTA) requirements for achieving the proposed impingement mortality reduction (80-95%) and [when applicable[1]] entrainment reduction (60-90%) performance standards for a CWIS. To comply with the proposed Section 316(b) regulations, a facility must:

- Demonstrate that it currently meets the specified performance standards;

- Select and implement design and construction technologies, operational measures, or restoration measures that meet specified performance standards; or

- Demonstrate that it qualifies for a site-specific BTA determination because the costs of compliance are either significantly greater than the costs that were considered by USEPA during development of the revised regulation, or the costs of compliance would be significantly greater than any environmental benefits that would be gained through compliance with the impingement and entrainment performance standards.

Thus, restoration is an option available to facilities on a voluntary basis to use alone or in combination with other technological measures to meet performance standards or in establishing BTA on a site-specific basis (USEPA 2002c).

Should a facility choose to employ restoration measures, the facility must demonstrate to the permitting agency that the restoration efforts will maintain the fish and shellfish (including community structure and function) in the water body at "a comparable" or "substantially similar level to" that which would be achieved by meeting the impingement mortality and, when applicable, entrainment reduction requirements (USEPA 2002c). This demonstration involves documentation in restoration planning and post-project implementation monitoring.

The USEPA's proposal strongly encourages facilities intending to pursue a restoration approach to consult with federal, state, and tribal fish and wildlife management agencies that have responsibilities for aquatic species potentially affected by a facility's cooling water intake structure (USEPA 2002c). Such consultation will:

- Identify the "species of concern;"

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1 The USEPA's proposal (USEPA 2002) requires an 80 to 95% reduction in impingement mortality by all Phase II power plants. Power plants on the Great Lakes, estuaries, tidal rivers, and oceans and whose capacity factor exceeds 15% must reduce entrainment by 60 to 90%. Power plants on rivers whose cooling water withdrawal exceeds 5% of the river's mean annual flow must also reduce entrainment by 60 to 90%. An exception to these performance standards, however, can be made for a site-specific determination of BTA as described herein (i.e., via the cost-cost or cost-benefit test).

- Identify the current status of species of concern located within the subject water body and provide life history information for those species, such as preferred habitats for all life stages; and

- Identify potential threats other than the CWIS to species of concern found within the water body (i.e., identify all additional stressors for the species of concern), appropriate restoration methods, and monitoring requirements to assess the overall effectiveness of the proposed restoration projects.

The USEPA stresses the importance of consultation because the agency believes that natural resource management agencies typically have the most accurate information available and thus are most knowledgeable about the status of the aquatic resource they manage.

The USEPA, as part of a Notice of Data Availability released in early 2003 (USEPA 2003), further clarified the benefits of restoration as a mitigation approach and requested comment on additional practices it may require. Specifically, USEPA is considering requiring the following practices during the development of restoration projects:

- Documentation of the sources and magnitude of uncertainty in expected restoration project performance;

- Creation and implementation of an adaptive management plan; and

- Independent peer review to evaluate restoration proposals.

Documentation of sources and magnitude of uncertainty and adaptive management are described in greater detail in Sections 4.2.4.5 and 4.4, respectively.

The USEPA believes that independent peer review addresses a major challenge to successful restoration, namely the coordination of information from a large number of scientific disciplines, particularly hydrology, landscape ecology, and aquatic biology. The USEPA believes thorough, multidisciplinary review of restoration proposals would help ensure their quality and, therefore, maximize the probability of project success. The USEPA is concerned, however, that thorough review of restoration proposals may place a significant additional burden on the review capacities of permit writers, the majority of whom are trained in the engineering sciences. To aid permit writers in their review of restoration proposals and to aid permittees in ensuring that the full range of pertinent expertise is brought to bear upon project plans, the USEPA is considering requiring that each facility restoration plan undergo an independent peer review prior to the plan's submission to the permit director. The USEPA is considering, and invites comment on, whether a facility should be required to choose the members of the peer review panel in consultation with federal, state, and tribal fish and wildlife management agencies with responsibility for the affected resources. The USEPA expects that the peer reviewers would be scientists who are otherwise independent of the permitting process for the facility and who, as a panel, have the appropriate multi-disciplinary expertise for the review of the restoration proposal. Peer reviewers would be charged with evaluating specific elements of each restoration proposal, such as descriptions of the uncertainty associated with restoration goals and projected outcomes, delays between project initiation and when a restoration program shows measurable success, and the nexus between impingement and entrainment losses and the ecological benefits of the proposed restoration program (USEPA 2003).

### *4.1.2 Effectiveness of Enhancement Alternatives for Addressing CWIS Impacts*

The environmental enhancements discussed in this report are widely used to restore or enhance natural resources. The effectiveness, advantages, limitations, and applicability of these enhancements for offsetting CWIS operational impacts are discussed in Chapter 2. While environmental enhancements have the capability to mitigate CWIS losses, it may not always be possible or desirable to mitigate impacts to a specific affected resource because of site-specific factors. In some cases, the enhancement may target species or age classes that differ from those incurring CWIS losses. In some cases, efforts to provide species-for-species mitigation may not be desirable, particularly if the affected species:

- Are nuisance or exotic species;
- Became established from past fishery management programs, but are no longer of interest or management focus; or
- Are common, widespread, abundant, or unimpaired and would derive little or no benefit from environmental enhancements.

Thus, acceptable environmental enhancements may not necessarily provide a species-for-species or life-stage-for-life-stage match when mitigating for CWIS impacts. Acceptable enhancements may be more broadly based, or more narrowly focused, than the CWIS impacts they are designed to offset.

For example, environmental enhancements may provide additional environmental benefits (e.g., flood control, habitat for other wildlife, pollution reduction, and recreation) that would not be provided by technological and operational measures focused solely on reducing CWIS impacts. Conversely, some enhancement approaches, such as stocking and fish passage restoration, may provide benefits for fewer species and life stages than other approaches such as habitat creation and restoration. An additional consideration is the period of time over which an enhancement will yield ecological benefits. While there may be a greater time lag for benefits of environmental enhancements compared with technological measures, the benefits may continue to accrue well after power plant operations have ceased (USEPA 2002c). For example, PSEG's wetlands restoration program and fish ladders are expected to continue providing environmental benefits even after the useful life of the plant has expired (Patterson 2001).

Environmental enhancements may also provide the requisite mitigation for CWIS losses, but at a lower economic cost than a technological mitigation approach. Thus, the potential to adequately mitigate impingement and entrainment losses and provide long-term environmental benefits, possibly at a lower cost, makes environmental enhancements a particularly attractive option for addressing CWIS operational impacts.

## 4.2 Framework for Selecting and Scaling Restoration Projects

A number of factors should be considered when evaluating and comparing alternative restoration projects and environmental enhancements. These factors (Pastorok and MacDonald 1996) include:

- Expected effects on target and non-target species;
- Potential for other environmental benefits, such as water quality improvements, flood control, and recreation;
- History of success or failure of similar enhancement efforts in the vicinity (e.g., fish stocking at other locations);
- Technical feasibility of the enhancements;
- Implementation, operation, maintenance, and monitoring costs;
- Projected time lag until specific enhancement goals are attained;
- Influence of other local activities on both the short-term and long-term enhancement success; and
- Regulator and stakeholder acceptance.

Numerous natural resource agencies use habitat restoration to mitigate environmental impacts, and some agencies have developed processes to facilitate their planning and evaluation of enhancement projects (USACE 1996, NOAA 1997). Common elements of these processes include:

- Identification of the injured natural resources;
- Identification of the restoration objectives;
- Identification of key ecological parameters to be manipulated or monitored;
- Identification of potentially applicable restoration alternatives;
- Evaluation of the type, quality, and value of natural resources and services provided by each restoration alternative relative to the impacted natural resource;
- Evaluation of project feasibility, cost, and environmental impacts; and

- Selection of approaches and methods to scale the restoration project to restore and/or replace injured natural resources.

Ultimately, the selection of an appropriate restoration project needs to be made on a case-by-case basis by using a combination of scientific information and best professional judgment, and will be based largely on the nature, extent, and magnitude of impingement and entrainment impacts occurring at the particular facility. The development of restoration projects should also consider potential population- and ecosystem-level impacts and losses of threatened and endangered, recreational, or commercially important species (Duke Energy 2002).

The selection and scaling of restoration projects to mitigate for CWIS impacts may be facilitated through the application of a framework similar to that employed by natural resource agencies that typically conduct environmental enhancement and restoration projects. For CWIS-related restoration projects, the following four-step framework may be useful:

1. Establish the baseline;

2. Consider technological and operational alternatives;

3. Select the restoration approach; and

4. Scale the restoration project appropriately.

This framework, described in more detail below, includes considerations of mitigation goals, technical feasibility, stakeholder involvement, ecological and technical practicality, and a variety of other factors identified above that are important to the defensible selection and scaling of an environmental enhancement program.

### *4.2.1 Establishing the Baseline*

Establishing the baseline serves to identify the species and life stages affected by impingement and entrainment and, in turn, serves to focus the development of restoration projects. Baseline information is important for determining whether it is necessary, appropriate, or even possible to directly mitigate losses to target species and life stages impacted by CWIS. Baseline information may also aid in determining if opportunities exist to obtain equivalent or greater environmental benefits by selecting an enhancement project that targets a specific life stage, an alternate species, or a completely different environmental resource. This step may also serve to establish the basis for the scaling of environmental enhancement projects.

The proposed rule (USEPA 2002) identifies a calculation baseline to be used as an estimate of impingement mortality and entrainment in the absence of impingement and entrainment controls. The calculation baseline is the basis from which to quantify all means of reducing impacts of impingement and entrainment, including intake location, flow reductions, screen improvements, and restoration. Since some means of reducing impacts may already be in place, the calculation baseline may require back-calculation of what impingement and entrainment impacts would be without these reductions so that credit can be assigned for existing mitigation. The calculation baseline is defined as the impingement and entrainment that would occur at a site assuming (1) a once-through cooling-water system, (2) a shoreline intake with standard screening technology (i.e., trash racks with 3/8-inch mesh traveling screens), and (3) similar practices and procedures to those that the facility would maintain in the absence of operational controls. The calculation baseline is thus intended by USEPA to establish a site-specific, baseline level of impingement mortality and entrainment under a partially standardized set of structural and operational conditions. Required reductions in impingement mortality and entrainment are then established relative to that baseline.

Instead of reducing impingement and entrainment, environmental enhancements would provide mitigation by increasing production of affected resources through the creation or improvement of environmental conditions or by stocking. Because of this difference, the calculation baseline identified by the USEPA (2002) is only one component of the baseline information needed to develop environmental enhancements. Components of the baseline for environmental enhancements include characterization of aquatic resources in the vicinity of the CWIS (through compilation of existing data or sampling) and the determination of impingement and entrainment losses. In some cases it may also be appropriate to include consideration of entrainment survival and calculate equivalent adult losses and/or foregone production.

Enhancement efforts usually rely upon providing or improving conditions to enhance the production of fish and/or invertebrates. As a consequence, the baseline should identify the resources that may be affected by environmental enhancements by including an evaluation of the status (e.g., numbers and life stages) of the aquatic biota that reside in or utilize the water body affected by the CWIS. This information will assist in the development of enhancements appropriate for the species and life stages in the affected watershed. As in the calculation baseline described above, the numbers of individuals, species, and life stages that are being impinged and/or entrained by CWIS operations need to be estimated so that enhancement projects can be scaled to compensate for the impacts to aquatic resources. Because entrained eggs and larvae may not incur 100% mortality, it may also be appropriate to consider entrainment survival in the determination of the baseline.

In some cases the environmental enhancement being considered will be unable to directly replace the species or life stages that are affected by CWIS operations. In such cases, the calculation of equivalent adult losses and/or foregone production may be appropriate for estimating how production (or stocking) of alternate life stages or increased food production affect adult population levels and overall productivity. The benefit expected from an environmental enhancement can then be compared with impingement and entrainment losses by using a common metric. Descriptions of equivalent adult loss and foregone production estimation are provided in Section 4.2.4.3.

In summary, the calculation baseline specified by USEPA (2002) in the proposed rule identifies the numbers and types of organisms that are being impinged and entrained by CWIS operations. If environmental enhancement projects are being considered as a means for addressing CWIS impacts, the calculation baseline needs to be augmented with information about the current status of aquatic resources in the watershed and, possibly, estimates of entrainment survival and the equivalent loss of adults or foregone production. By comparing estimated CWIS losses (as equivalent adults and/or production foregone) to comparable measures of benefits (e.g., increased fish production) from environmental enhancements, enhancement alternatives and enhancement levels can be formulated. This process provides a quantitative basis for evaluating enhancement alternatives and scaling the selected alternative to adequately mitigate for impingement and entrainment losses. EPRI is currently preparing guidance on how to determine the calculation baseline and how to conduct impingement and entrainment monitoring. EPRI recently completed a review of entrainment and impingement survival studies (EPRI 2000 and 2003, respectively) and is in the process of developing guidance for conducting entrainment survival monitoring. Detailed guidance for calculating equivalent adult losses and production foregone is also being developed by EPRI.

### *4.2.2 Consideration of BTA Alternatives*

The USEPA and case law interpreting Section 316(b) have long interpreted this statute to require consideration of both technological and economic feasibility, as well as impacts not related to water quality, of alternative technologies in determining the applicability of a given technology for mitigating impingement and entrainment impacts. Technological alternatives whose costs are "wholly disproportionate" to the environmental benefits to be gained or whose non-water-quality-related impacts cannot adequately be addressed are considered "infeasible" or "not available" and, thus, do not qualify as BTA (USEPA 2002c). For example, regulators accepted the determination that the estimated $93-$124 million costs of cooling water alternatives at Northeast Utilities' Millstone Nuclear Power Station to benefit winter flounder were unwarranted considering the relatively small benefit that the species would have realized (ORNL 1999).

In such situations, the USEPA has allowed facility operators to satisfy BTA requirements by implementing habitat restoration programs to compensate for impingement and entrainment losses (Patterson 2001, Duke Energy 2002). The use of environmental enhancements in lieu of technological changes in facility design or operations is voluntary, and BTA determinations will be site specific. For example, the costs of retrofitting the Crystal River Power Plant with a closed-cycle cooling system were determined to be disproportionate to the environmental benefits to be gained. As a result, the USEPA accepted the applicant's proposal to construct a fish hatchery as mitigation (Patterson 2001).

While the benefits from a technology change (e.g., change from once-through to closed-cycle cooling systems) are only realized over the life cycle of the modernized plant, the benefits of habitat enhancements can be realized beyond the expected life of the facility, and may benefit other species and the entire watershed (e.g., flood control, pollution reduction, and improved recreation). Thus, in some cases, plant upgrades may provide less of an environmental benefit and cost more than an environmental enhancement alternative (California Regional Water Control Board 2003). For example, PSEG's wetlands restoration program and fish ladders (which were voluntarily proposed by PSEG) are expected to continue to provide benefits to fish and wildlife even after the useful life of the Salem Generating Station has expired (Patterson 2001).

Technological and/or operational changes can also be used in combination with environmental enhancements where enhancements, technology, or operational changes alone would not reduce CWIS operational impacts to acceptable levels. For example, at the Chalk Point Generating Plant on the Chesapeake Bay estuary, barrier nets were used to reduce impingement losses, while a fishery enhancement program was used to mitigate entrainment losses because neither approach would individually address all impacts (Bailey et al. 2000). Duke Energy's Habitat Enhancement Program (HEP) for the Morro Bay Power Plant in California includes the identification, analysis, and funding of habitat enhancement projects in Morro Bay and the upland watersheds of Los Osos and Chorro Creeks, as well as new power plant design features and cooling system flow restrictions (Duke Energy 2002).

The proposed Section 316(b) regulations would also allow existing facilities to take credit for previously installed technologies that reduce impingement and entrainment (USEPA 2002c). Taking such credit could alter the baseline condition (Section 4.2.1) and affect the amount or type of environmental enhancement that may be needed to mitigate CWIS losses. Thus, a less costly restoration project might be implemented to make up the difference between what is achieved by previously deployed technology and the performance standard.

Thus, the relative cost, feasibility, and environmental benefits of using alternative technologies or operational measures must be considered when determining how to address impingement and entrainment impacts of CWIS operation. EPRI (1999, 2000) has prepared reviews of technologies and the BTA selection process and is currently updating those reviews to include detailed information on the costs associated with retrofitting technologies. This update is expected to be available in 2004.

### *4.2.3 Selecting the Restoration Approach*

Selection of the appropriate restoration approach should be viewed as a project scoping and planning activity. Most of the environmental enhancement alternatives discussed in this report may provide CWIS impact mitigation by restoring or creating habitats in order to increase growth, survival, or reproduction of aquatic biota and thus indirectly offset impingement and entrainment losses (see Chapter 2). This contrasts to direct replacement of impinged or entrained biota through stocking. The suitability of any particular environmental enhancement for a restoration project will be a function of the water body type, water quality, local geomorphology, and local fishery management objectives. In some cases, a single cost-effective restoration measure may be readily identified on the basis of fishery or water-body-specific issues. In other cases, a number of alternatives or combinations of alternatives may seem appropriate and thus require evaluation. In addition, as previously discussed, a combination of environmental enhancements and technological and/or operational plant modifications may be considered applicable for mitigating impingement and entrainment impacts of CWIS operation.

Factors to be considered when evaluating and selecting among alternative restoration projects include the following:

- Types of biota (recreationally or commercially important, threatened or endangered, native or exotic, etc.) that will be benefited;
- Ability of the enhancement approach to benefit specific biota, and the likely response of target and non-target biota to the enhancement;
- Likelihood of success;
- Status (common, rare, abundant, affected by non-power-plant anthropogenic impacts) of target and non-target species and habitats in the area that would be affected by the enhancement;
- Availability of suitable areas at which to implement a specific enhancement approach;
- Evaluation and quantification methods for translating impingement and entrainment impact levels to a compensatory level of environmental enhancement, and the uncertainties associated with these methods;
- Technical feasibility and cost; and
- Regulatory and public acceptance.

Despite a substantial body of information addressing wetland mitigation and restoration, restoration of aquatic systems such as estuaries continues to be complex and evolving (USEPA 2002c). Thus, many enhancement projects should be partly viewed as experiments with built-in monitoring and research designed to advance understanding and improve the quality of future restoration activities, the predictability of restoration outcomes (Goodwin et al. 2001), and funding for research and monitoring should be considered as part of any restoration project (RAE-ERF 1999). Ultimately, the selection of enhancement approaches will involve consultation with federal and state resource agencies and possibly other appropriate stakeholders together with consideration of the mitigation objectives and ways in which various enhancement alternatives may be combined to meet those objectives.

The outcome of this step should be a clear identification of the mitigation objectives of the restoration program, identification of the enhancement targets (the species, habitats, water quality, or other areas of focus), and an explicit rationale for selecting those objectives and targets. Consultations may also help ensure that the project receives necessary approvals and that issues of concern to stakeholders are identified and resolved early in the planning process so that conflicts can be avoided later in the process.

#### 4.2.3.1 Consultation

Consultations and negotiations among the facility, regulators, and other stakeholders are important components in the determination of the restoration and enhancement objectives and approaches. Consultations may also help ensure that a project receives necessary approvals and that issues of concern to stakeholders are identified and resolved early in the planning process so that later conflicts can be avoided. Natural resource agencies and organizations with which consultations may be appropriate include:

- Federal agencies (e.g., USFWS, NMFS, NOAA, and USACE);
- State and regional commissions (e.g., ASMFC, California Coastal Commission, Potomac River Fishery Commission);
- State fish and wildlife departments;
- Fishing clubs or other local sportsman associations (e.g., Ducks Unlimited);
- Local watershed organizations formed to address water quality issues; and
- Environmental organizations (e.g., The Nature Conservancy, Isaac Walton League).

For example, in developing its Estuary Enhancement Program in Delaware Bay, PSEG worked with members of the scientific community as well as a variety of governmental agencies. An advisory committee was formed to assist in project development and implementation. The committee included scientists with expertise in aquatic ecology and wetland restoration that were affiliated with universities and research centers (Woods Hole Oceanographic Institution, Stevens Institute of Technology, and Louisiana State University's Coastal Ecology Institute), as well as federal agencies (USFWS, USACE, USGS, and NMFS) (PSE&G 1996a-c, Weinstein et al. 2001). The committee also included representatives from federal, state, regional, and local regulatory agencies, such as the New Jersey Department of Environmental Protection (NJDEP) and the Delaware Department of Natural Resources and Environmental Control. Extensive negotiations with these and other stakeholders resulted in development of PSEG's Estuary Enhancement Program, directed toward the restoration, enhancement, and preservation of more than 10,000 acres of salt marsh and adjacent uplands. Participants in PSEG's Estuary Enhancement Program have also included independent scientists, environmental groups, community leaders, public officials, watermen, sportsmen and other stakeholders (PSE&G 1996c).

The development of the Habitat Enhancement Program (HEP) by Duke Energy (2002) for its Morro Bay Power Plant is another example of effective consultation. The principal objectives of this program are to improve the overall quality and quantity of certain aquatic habitats in Morro Bay, reduce sediment transport to the bay, and complement ongoing programs for bay protection and enhancement being carried out by other agencies and organizations (e.g., California Regional Water Quality Control Board [CRWQCB], the National Estuary Program, USACE)

(Duke Energy 2002). In cooperation with the CRWQCB, the HEP was developed to include projects to restore or enhance in-bay habitat and to preserve habitat through watershed management efforts. The National Estuary Program had identified sedimentation as the primary ecological stressor affecting Morro Bay (Duke Energy 2002). Although the power plant does not contribute to sediment buildup in the bay, the mitigation program includes habitat enhancement projects to restore coastal salt marsh through removal of accumulated sediment and to preserve existing habitat through watershed management activities that reduce in-bay sedimentation. Thus, local regulators saw the HEP as an effective entrainment mitigation alternative because the reduced sediment loading would result in significant benefits to the fish and invertebrate populations affected by entrainment by preserving habitat critically important to those species (California Regional Water Control Board 2003). In addition to offsetting entrainment effects, the HEP is expected to enhance the overall quality and quantity of habitats in the estuary (Duke Energy 2002).

One goal of consultations is to identify the current status of species of concern located within the subject water body and to provide life history information for those species and life stages (USEPA 2002c). Consultation topics may include potential threats to species of concern within the water body, restoration methods, and monitoring requirements to assess the overall effectiveness of proposed restoration projects. Natural resource management agencies often have the most accurate information available and are most knowledgeable about the status of the watershed and aquatic resources potentially affected by CWIS operations (USEPA 2002c).

While restoration project planning should focus on scientific and technical issues, community perspectives and values should not be overlooked. If involved in the restoration process, public and private organizations that may be affected by the enhancement project can help build the support needed to get the project moving and ensure long-term protection of the restored area. In addition, partnership with stakeholders can add useful resources, ranging from supplemental or collaborative funding and technical expertise to volunteer help with implementation and monitoring (see Section 2.6). Cooperation between energy companies, regulators, natural resource agencies, conservation organizations, and the concerned public can lead to management agreements, mitigation projects, conflict-avoidance programs, program support, and volunteer programs while enhancing project progress (Sawhill 1996). In addition, coordination may identify opportunities for coordinating and/or partnering the restoration project with other existing protection and enhancement programs that may be occurring in the same watershed (Duke Energy 2002). Furthermore, such programs may provide valuable information regarding lessons learned and species and watershed responses and may provide opportunities to partner with these other programs. Thus, at many levels consultation can bring significant benefits.

#### 4.2.3.2 Identifying Restoration Objectives and Suitable Enhancement Approaches

Restoration objectives may be site-specific and target only those species directly affected by impingement and entrainment, they may target species indirectly or not at all affected by CWIS operations, or they may focus on water quality, habitats, or even entire watersheds. The identification of restoration objectives will be affected by a variety of considerations, including current environmental conditions, the types and numbers of species affected by impingement or entrainment, cost, the target species or target ecological services expected to benefit from the enhancement project, the availability of suitable sites for implementing enhancement approaches, and potential for enhancements to benefit resources not affected directly by CWIS operations. In addition, the identification of restoration objectives may be strongly influenced by discussions and negotiations with regulators, resource agencies, the public, and other appropriate stakeholders.

Development of restoration objectives that directly or indirectly target species incurring CWIS operational losses will require an understanding of the ecological requirements of the targeted species, as well as an understanding of the ecosystems that support them. For example, the marsh restoration goals of the restoration program developed for mitigating impingement and entrainment impacts at the PSEG Salem Generating Station were based upon the understanding that the primary production of salt marshes directly affected secondary production of estuarine and marine species (Weinstein et al. 2001).

Prior scientific research provided information on the ecology and natural history of the species of concern, as well as of consumer organisms in the Delaware Estuary food web (NJDEP 2000, Weinstein et al. 2001). Tidal salt marsh wetlands in the estuary provide foraging, refuge, and nursery habitats for early life stages and juveniles of these species and provide food resources to these and other species throughout the estuary. Published scientific literature indicated that tidal salt marshes that supported communities of native plant species were important to the productivity of Delaware Bay fish. One species, *Spartina alterniflora*, was found to be particularly important in creating the physical structure for fish habitat, as well as production of live plant material and detritus for forage within the marsh. Export of *Spartina alterniflora* detrital biomass to Delaware Bay had also been shown to be an important source of energy to the bay ecosystem and to support fish production in the bay (Weinstein et al. 2001).

#### 4.2.3.3 Combining Alternative Enhancement Approaches

In some cases, acceptable mitigation of CWIS environmental impacts may be achieved through a combination of environmental enhancement approaches rather than implementation of any single approach. Factors affecting the use of enhancement combinations may include cost differences between small- and large-scale enhancements; expected levels of success of different enhancement approaches within the watershed of interest; the availability of appropriate areas for implementing individual enhancement options; and the resources of most concern to regulators, natural resource agencies, the public, and other potential stakeholders. For example, sufficient locations for wetland creation/restoration may not be available to produce the necessary level of impingement and entrainment mitigation. However, the proximity of a small dam could allow for the restoration of fish passage that together with a smaller wetland restoration could result in fish productivity levels that provide acceptable mitigation.

As an example of combining different environmental enhancements, PSEG implemented a combination of fish passage restoration, wetland restoration, and stocking to increase fish production and compensate for CWIS operational losses at its Salem Generating Station. The Estuary Enhancement Program was designed to provide long-term benefits to the Delaware

Estuary by increasing the production of fish and other aquatic biota through expansion and protection of habitat for spawning, foraging, and growth. In addition to wetlands restoration and enhancement activities, the program also included the construction of eight fish ladders for river herring migration that opened access to 100 miles of river and 700 acres of spawning habitat. PSEG is working with NJDEP to select appropriate sites for two additional fish ladders from among a number of sites recommended by the USFWS. In order to expedite the return of river herring to spawning and nursery areas above the new fish ladders, PSEG transported and released ripe river herring above the dams. This procedure will continue until a target number of fish per acre pass through the fish ladders.

A combination of enhancement approaches, technological applications, and funding support is being used to support required mitigation for the San Onofre Nuclear Generating Station (SONGS) in Southern California. The SONGS mitigation program includes restoration or creation of at least 150 acres of wetlands, installation of fish barrier devices at the CWIS, and construction of a 300-acre kelp reef (to compensate for thermal discharge impacts under Section 316[a]) (Ambrose 1994a, Johnson et al. 1994, Deysher et al. 2002). In addition, SONGS is providing funds for scientific and support staff to oversee site assessments, project design and implementation, and monitoring, and to partially pay for construction of an experimental white sea bass hatchery (Duke Energy 2002).

Required mitigation by Mirant for their Delta Contra Costa and Pittsburgh plants in California includes the restoration of tidal flow by creating openings in dikes along the Sacramento River and the creation of three sloughs to increase three tidal marsh zones, along with a variety of aquatic and terrestrial conservation activities for selected species at the Montezuma Enhancement Site (Duke Energy 2002).

#### 4.2.3.4 Enhancing Species Not Incurring CWIS Operational Impacts

In some cases, the target of an environmental enhancement project may differ from the biota incurring the impingement and entrainment impacts of CWIS operation. As discussed earlier, if the impacted species are considered to be of little value (e.g., exotic fish), are not expected to benefit from mitigation, or are of less interest to regulators and other stakeholders, an enhancement alternative may be selected that benefits different species, such as state or federally protected species, commercially important fishes, or forage species that are important prey for more valuable fishes.

For example, the striped bass, shad, and yellow perch hatchery and stocking programs associated with entrainment compensation for the PEPCO Chalk Point facility did not address the primary species incurring CWIS impacts, but benefited species that have been historically impacted by overfishing and water quality degradation (Willenborg 1999). Other components of the required entrainment compensation included $100,000 yearly funding for environmental education and projects to remove obstructions to anadromous fish migration. These activities targeted species not directly impacted by impingement and entrainment at the facility.

Another example of mitigating CWIS environmental impacts by targeting non-impacted species is also provided by the PSEG Salem Generating Station program. Although river herring (alewife and blueback herring) were not identified as species impacted by CWIS operations, these species were found to be important forage for some of the species that did incur losses at the generating station (NJDEP 2000). Restoration of fish passage to tributary streams of Delaware Bay resulted in an increase in the productivity of river herring, which in turn was expected to provide a benefit to the species of interest, as well as to other commercially and recreationally important fish species.

An example of mitigating entrainment losses by targeting a water quality parameter can be found in the Habitat Enhancement Program for the Morro Bay Power Plant. To mitigate for entrainment losses, the program attempts to reduce sediment transport to Morro Bay, even though the plant is not a source of sediment loading to the bay (Duke Energy 2002). This objective will be addressed through the removal of accumulated sediment in coastal salt marsh habitats and implementation of watershed management activities (e.g., vegetated riparian buffers, sediment traps, stream channel restoration) to reduce in-bay sedimentation.

### *4.2.4 Scaling the Restoration Project*

Once a restoration project has been identified, it must be appropriately scaled to meet the mitigation goals. Scaling refers to the determination of the quantity of the environmental enhancement needed to restore or replace the resources impacted by CWIS operations.

NOAA (1997) identifies a resource-to-resource approach for determining the amount of a resource that must be provided in order to replace or restore the resource that was lost or impacted; it implies a one-to-one relationship between the impacted and restored resource. While this one-to-one assumption may be appropriate for stocking, it is not applicable for the other environmental enhancement options addressed in this report (see Chapter 2).

Most of the environmental enhancement alternatives discussed herein provide mitigation not by direct replacement of biota but rather by providing new or restored habitat to increase production of aquatic biota and thereby offset impingement and entrainment losses. The underlying assumption of such an approach is that compensation for impacted natural resources can be provided by enhancement projects that provide comparable replacement of resources.

A number of issues must be considered when scaling an enhancement project. These issues include:

- Current environmental conditions in the watershed,
- Restoration goals, including target species or resources,
- Knowledge of ecosystem productivity in the project area,

- Availability of metrics for relating CWIS losses to expected enhancement-related gains in productivity levels,
- Use of multiple metrics,
- Adjusting the project scale to address uncertainty associated with predicted enhancement success,
- Natural, temporal variability in ecological conditions,
- Monitoring requirements, including development of resource-specific success criteria, and
- Time lags between implementation and biological response.

Scaling is more difficult when multiple species are involved, when common metrics are not readily available, when the target species differ from those incurring impacts, and/or when the mitigation goals target resources other than those incurring impacts. In most cases, the greatest complexity associated with scaling is associated with quantifying the increment in biological productivity expected from a given change in the physical habitat. For example, a variety of approaches have been used to quantify fish productivity per unit of wetland. However, each employs different assumptions regarding nutrient flow, energy production, trophic relationships, and fish production.

#### 4.2.4.1 Scaling Restoration Projects Using Habitat Equivalency Analysis

Habitat equivalency analysis (HEA) is an analytical method developed by NOAA to quantify natural resource and service reductions associated with oil spills and to scale the amount of restoration needed to compensate the public for those natural resource losses (NOAA 1997, 2000, Peacock 2001, Penn and Tomasi 2002, Strange et al. 2002). The term services refers to the ecological functions that can address impacts to biota, such as providing spawning, nursery, and foraging habitats. HEA is widely used by numerous state and federal resource agencies to scale restoration projects in a variety of regulatory contexts (such as the Oil Pollution Act, CERCLA, and the Park System Resource Protection Act). The advantages of using HEA over traditional economic valuation approaches is that, under HEA, losses and gains of natural resources are estimated using ecologically based metrics rather than assigning monetary values to the losses and gains (Duke Energy 2002). In addition, HEA can reflect ecological variability and complexity when evaluating restoration or enhancement projects (Strange et al. 2002).

The underlying assumption in HEA is that compensation for impacted natural resources and their services can be provided by restoration projects that yield comparable replacement of resources and services (NOAA 2000, Peacock 2001). Thus, it is an approach to scaling that can be applied when the impacted and mitigated resources are not of comparable value (e.g., impinged fish vs. restoration of fish passage), as long as there is a resource or metric common to both the impacted and mitigated resources. It should be noted, however, that while impingement and entrainment directly affect some species, they do not degrade or destroy habitat.

As part of its Habitat Enhancement Program, Duke Energy Morro Bay LLC employed HEA analysis to scale eelgrass and salt marsh creation (in acres) to mitigate for fish and crab biomass (in kilograms) entrained at its Morro Bay Power Plant (Duke Energy 2002). This HEA analysis required (1) estimation of biomass entrained over the life of the power plant, (2) estimation of eelgrass and marsh productivity in the bay on which the power plant is located, (3) conversion of eelgrass and marsh productivity to fish and crab biomass produced per acre per year, and (4) estimation of the total fish and crab biomass generated over the lifespan of the power plant. This information was then used to estimate acres of habitat that would be needed to compensate for the crab and fish losses.

#### 4.2.4.2 Species Considerations for Scaling

Different species will exhibit different production levels in similar habitats. Thus, it is important to consider the relative production by various fish species in particular habitat types. When multiple target species can be produced within a particular habitat type, it may be most appropriate to scale the restoration effort on the basis of the species with the lowest level of production. For example, PSEG's 1994 NJPDES permit stated that just under 7,500 acres should be restored to increase fish productivity to a level that equals the fish estimated to be destroyed by the CWIS. The species of concern were bay anchovy, white perch, spot, and weakfish. The final restoration area was based primarily on mortality estimates for the bay anchovy, which resulted in the highest acreage determination. Because the acreage needed for the various species were not considered additive, the largest amount of acreage required for any given species was considered to be protective of all the target species and was selected as the scale for the wetlands project. In fact, it was estimated that production of other species would exceed the level of fish lost to impingement and entrainment (Patterson 2001).

#### 4.2.4.3 Scaling Metrics

The key to scaling is the use of a common metric that relates the benefits of the restoration project (i.e., the environmental enhancement) to the CWIS operational impacts. The use of a common metric not only provides for a defensible means of scaling, but also provides support for the use of that particular enhancement for mitigating impacts. Use of a common metric, however, will most likely involve any number of methods for estimating that metric. The two most common metrics are fish number and fish biomass.

For example, a wetlands restoration project may be selected to mitigate entrainment impacts by providing for the production of a certain number of a particular age class of fish (deemed important as a result of discussions and negotiations among appropriate stakeholders). The metric common to both the CWIS impacts and the restoration is the number of fish of a particular age class. To scale the restoration project, first an estimate would be needed of the number of the specific age class fish that would not be produced as a result of the number of eggs and/or larvae lost to entrainment at the CWIS. This requires a method for translating numbers entrained into a corresponding number of fish of a specific age (e.g., age 1).

Secondly, an estimate would be needed of the number of fish of that age that could be expected to be produced per unit area of restored wetland. Different methods would be needed to translate wetland primary productivity into production of fish biomass of the appropriate species and age classes. Alternatively, the production of food resources attributable to a given area of wetland may be estimated and then used to predict how many additional fish could be supported by this additional food base.

In all cases, scaling will require ecological information (such as diet, foraging habitat, predation rates, natural mortality rates, and growth rates) for the target species and information on the productivity of the selected enhancement approach.

Methods that have been used for translating fisheries losses (including losses from impingement and entrainment) and mitigation approaches to a common scaling metric include:

- Direct replacement,
- Production of equivalent adults,
- Foregone production,
- Production of equivalent biomass,
- Energy transfer and food chain models, and
- Fish replacement values.

Aspects of these various metrics and methods for calculating them are discussed below. EPRI will publish detailed guidance on calculating equivalent adults and production foregone losses in 2004; the basics of these approaches, however, are reviewed in Goodyear (1978), Rago (1984), Jenson et al. (1988), EPRI (1999, 2002), and Dey (2003). Each method has its advantages and limitations with regard to data needs, uncertainties, and applicability for scaling specific enhancement alternatives (e.g., wetlands creation, fishway installation) (Table 4-1). While these methods may be used individually, they are typically used in some combination.

***Direct Replacement.*** Direct replacement (or individual loss) involves the absolute number or weight of fish that are lost to impingement and entrainment from CWIS operation. As an enhancement metric, direct replacement is conceptually simple; requires minimal information, effort, time, and expertise; is easy to measure; and is readily understood and accepted by non-experts (EPRI 2002). Another advantage of direct replacement is that if the numbers of individuals impinged and entrained for a given species are very low relative to the expected size of the population, it would be possible to eliminate that species from further consideration (EPRI 2002). The primary disadvantage of direct replacement is that it is only weakly related to the assessment endpoint (e.g., population or community). Also, direct replacement does not provide a quantification of density-dependence or multiple stresses (EPRI 2002). For example, winter stress may cause impingement levels to be high. However, the fish impinged are largely dead or

**Table 4-1**
**Advantages and Limitations of Methods Used for Scaling Environmental Enhancements.**

| Method | Advantages | Limitations |
|---|---|---|
| Direct replacement | Limited data needs; modeling not required; low level of uncertainty. | No quantification of density-dependence or multiple stresses; primarily applicable to stocking. |
| Equivalent adults | Limited data needs. | Uncertainties associated with estimating production of specific age classes by habitat. |
| Production foregone | Can estimate production of both prey and predator species. | Complex analytical equations; high data requirement needs; uncertainties in estimating habitat productivity; must translate to impinged and entrained species. |
| Equivalent biomass | Limited data needs; uses estimated habitat productivity for scaling. | Uncertainties in estimating habitat productivity; must link biomass to biomass of target species. |
| Energy transfer and food chain models | Can estimate biomass of fish production per unit of habitat area; can be coupled with adult equivalent, production foregone, or equivalent biomass estimates to scale habitat restoration projects. | Tend to be complex and data-intensive; may have a high degree of uncertainty in biomass estimates. |
| Replacement values | Provides a defensible estimation of monetary value of impingement and entrainment losses; valuation of all species. | No direct connection to species numbers or biomass; primarily used for monetary compensation of impingement and entrainment losses. |

moribund individuals that would be lost from the fishery regardless of whether they would be impinged (LaJeone and Monzingo 2000).

***Equivalent Adults.*** Because impingement and entrainment losses often include multiple life stages for a given species, total losses are generally expressed as equivalent losses of a single, common life stage. The Equivalent Adult Model (Goodyear 1978, Dey 2003) is used to express impingement and entrainment losses (generally based on CWIS monitoring studies) as an equivalent number of individuals at some specified life stage. This specified life stage is referred to as the age of equivalency. The age of equivalency can be any life stage of interest, such as age 1. For any given species, the model estimates the number of individuals annually lost to impingement and entrainment that would otherwise have been expected to survive to the age of equivalency. Estimates of survival to the specified age of equivalency are generally derived from natural and fishing mortality rates available in the scientific literature or from natural resource agencies, although estimates for all life stages for a species may not be available (Goodyear 1978, EPRI 1999, 2002, Dey 2003).

The model provides a convenient means for converting losses of eggs and larvae into units of individual fish, and provides a standard metric that can be used to compare losses among species, years, and facilities. The number of equivalent adults, or other life stage, can be used to determine the number of fish that should be stocked (when not directly replacing impinged or entrained life stages), or to determine the area of a specific habitat type that would be needed to compensate for the loss. If the scaling metric selected is biomass rather than number of organisms, the age equivalent loss estimates can be converted to a total weight for each species using the average weight for the age class. Acres of habitat required to offset CWIS losses could then be estimated from the expected biomass production of that age class for a specific habitat type. Information needed to scale a restoration project would include habitat utilization by the species and age class of concern, and the number of individuals within each designated age class. If the age equivalent loss estimates are converted to total weight, information necessary for an energy transfer or food chain model would be required to estimate biomass production of the species of concern (see Equivalent Biomass, below).

Advantages of the Equivalent Adult Model include the limited data requirements, ready availability of mortality and growth rates for many commercially and recreationally important fish species, and relatively low levels of uncertainty. Limitations of this method include the lack of information on mortality and growth rates for some species or age classes (EPRI 1999, 2002, Dey 2003).

***Production Foregone.*** The Production Foregone Model (Rago 1984, Jensen et al. 1988) estimates the additional biomass that would have been produced by a population in the absence of impingement and entrainment losses. The model estimates potential future production of individuals of species that would be impinged or entrained by using estimated life-stage-specific losses. Estimates of growth and survival, based on species-specific growth curves and species-specific survival curves available from scientific literature or developed from site-specific studies, are used to calculate future production (EPRI 1999, 2002). The model uses growth rates, survival rates, and average weight for each age class identified in CWIS operational losses, although a version of the model has been developed that does not require growth or survival rates. Since foregone production may represent lost food resources for higher trophic levels, it can also be calculated to assess the indirect impact on piscivorous species that do not experience impingement and entrainment.

This model provides a means of converting CWIS losses into foregone future growth of fish species of interest using biomass as the metric. The foregone production estimate can be used to determine the area required for habitat restoration or creation. Information on habitat utilization and food requirements of the species of concern would be required for determining the relevant habitat types and for scaling. Acres of habitat required to offset impingement and entrainment losses could be estimated by multiplying the foregone production of a given species by the per-acre productive capacity of that habitat for that species. The per-acre productive capacity of the habitat can be estimated using an energy transfer or food chain model (see Equivalent Biomass, below).

An advantage of the Production Foregone Model is that direct comparisons can be made between the species-specific foregone production of the age-specific lost organisms (e.g., eggs or larvae) and the production of the species and age class of interest in the specific habitat types considered as potential enhancements. In addition, the model can be used to estimate both direct effects on predatory and prey species and indirect food chain effects on predatory species. Application of the Production Foregone Model may be constrained by availability of the requisite information or life-stage-specific growth and survival rates and uncertainties in estimating biomass productivity in created or restored habitats.

***Equivalent Biomass.*** The equivalent biomass procedure converts entrainment numbers to biomass, calculates the amount of biomass entrained by the power plant, estimates habitat primary productivity, converts that habitat productivity estimate to a per-acre rate of biomass production of target species in the restored habitat (using an energy transfer model), and then calculates the habitat acres needed to provide that level of production by dividing the required biomass production by the per-acre production of restored habitat (Duke Energy 2002). For example, as part of its HEP, Duke Energy employed HEA to determine proposed wetland and estuarine restoration and preservation requirements (in acres) to mitigate for fish and crab biomass (in kilograms) entrained at its Morro Bay Power Plant (Duke Energy 2002). This analysis required (1) estimation of biomass entrained over the life of the power plant, (2) estimation of eelgrass and marsh productivity in the bay on which the power plant is located, (3) conversion of eelgrass and marsh productivity to fish and crab biomass produced per acre per year, and (4) estimation of the total fish and crab biomass that would be generated over the estimated lifespan of the power plant. This information was then used to estimate the acres of habitat that would be needed to compensate for crab and fish losses from entrainment

Thus, fish biomass is an ecosystem-level link between CWIS losses and the gains in primary production achieved through an environmental enhancement. Limitations of this approach may include a lack of available data on food web components and trophic structure for some locations and of requisite ecological data for some species. Uncertainties in the analysis, however, can be accommodated by applying an agreed upon safety factor to the estimated amount of habitat required to offset entrainment (Teal and Weinstein 2002).

***Energy Transfer and Food Chain Models.*** While methods such as equivalent adult production and production foregone can be used to quantify estimates of impingement and entrainment losses from CWIS operations, these methods do not provide adequate estimates of additional fish production resulting from habitat creation or restoration. Energy transfer and food chain models are often used to estimate production of fish and macroinvertebrates resulting from habitat creation and restoration projects (Deegan et al. 2000, Patterson 2001, Weinstein et al. 2001, Duke Energy 2002). In general, energy transfer and food chain models estimate primary productivity for a particular habitat and then model the flow of energy or biomass from the primary producers through food webs to higher trophic levels and selected species.

Energy transfer and food chain models can be used to estimate fish biomass produced per acre of habitat by modeling time conversion of plant productivity to fish biomass through the food chain (Patterson 2001, Weinstein et al. 2001). An energy transfer model was used at Duke Energy's Morro Bay facility to estimate the fish and crab biomass production per acre of restored wetland per year (Duke Energy 2002) on the basis of the primary production of eelgrass and coastal marsh habitats. The estimated fish biomass production per unit of habitat area can then be coupled with adult equivalent, production foregone, or equivalent biomass estimates to scale a habitat restoration project. For example, PSEG employed a linear food chain model using total plant biomass to calculate the wetland area required to produce the biomass of fish equivalent to that impacted by the power plant CWIS (Weinstein et al. 1997, 2001).

Because energy transfer or food chain models may be very complex, they can also be very data intensive. While simpler models may be developed, such models may have a high degree of uncertainty associated with their biomass productivity estimates. Such simple models may be useful, however, for developing scaling estimates for use in preliminary project planning meetings and negotiations.

Data needs associated with these models include the trophic structure of the habitat of interest, primary productivity rates, trophic transfer efficiencies, and habitat utilization and growth rates for relevant species (Deegan et al. 2000). Other information that has been used in such models includes the amount of land-water interface, water temperature, turbidity, vegetation structure, geomorphology, frequency and duration of flooding, tidal range, and detrital decomposition rates (Deegan et al. 2000, Weinstein et al. 2000a). Data sources may include the open scientific literature and natural resource agency reports, as well as site-specific or watershed-specific studies (EPRI 1999).

***Fish Replacement Value.*** Enhancement or restoration to compensate for CWIS operational losses could also be scaled based upon the economic value of the organisms that are affected. For example, the American Fisheries Society (AFS) has compiled estimates of the replacement values of various fish species, organized by geographic region and fish size, on the basis of the average cost of hatchery-raised fish (AFS 1992). These values, derived from surveys of public, private, and tribal fish hatcheries in the United States, are commonly used by management agencies to determine monetary compensation for fish kills. Using the supplied information, together with information about the number of fish affected by CWIS operations, it is possible to establish the total monetary value for the affected organisms.

The simplest use of the resulting valuation to scale restoration projects would be to establish the number of organisms that must be stocked (e.g., based on production costs) or the amount of money that must be spent to compensate for the value of the affected fish. For example, Maryland regulations require facilities with CWISs to spend up to 5 times the annual value of fish and crabs impinged based on the valuations compiled by the AFS. For Mirant's Chalk Point Facility on the tidal Patuxent River, this resulted in approximately $2.25 million in liability over a 5-year period (Bailey et al. 2000).

Alternatively, the replacement valuation method could potentially be used to determine the amount of habitat that would be needed to produce organisms (not necessarily the same species affected by CWIS operations) of a value equivalent to the value of impinged and entrained biota. An energy transfer model could be used to develop an estimate of the numbers, species, and sizes of organisms that could be produced per unit area of habitat. A fish replacement value could then be assigned to the habitat unit, and the restoration project could be scaled to compensate for the replacement value determined for the impinged and entrained fishes.

#### 4.2.4.4 Use of Multiple Scaling Metrics

In most cases, a variety of metrics for estimating CWIS operational losses and productivity of the proposed restoration activity will be needed to scale the environmental enhancement project. For example, an equivalent biomass method was used at the Morro Bay Power Plant to estimate fish and crab entrainment losses, while an energy transfer modeling approach was used to predict the biomass of fish and crab that would be produced per acre of restored wetland. These results were then used to scale the wetland restoration project (Duke Energy 2002).

The use of multiple methods for estimating facility impacts and restoration project benefits, especially if the results are complementary, can give stakeholders added confidence that the scale of the selected mitigation project is appropriate. For example, PSEG (Patterson 2001) provided loss estimates in its permit application in several ways:

- Fish number and density (fish/$m^3$);
- Conditional mortality rates (CMRs) for the local Delaware River portion of young-of-the-year population;
- Age 1 equivalent recruits;
- Production foregone estimates of the total reduction in future growth (measured in units of biomass);
- Spawning stock biomass per recruit; and
- Equilibrium stock size (based on spawner recruit analysis).

#### 4.2.4.5 Use of Safety Factors

The outcome of restoration projects, regardless of the nature of the project (e.g., stocking, artificial reef construction) or the context under which it is being carried out (e.g., impingement and entrainment mitigation, wetlands compensation required under an Army Corps of Engineers wetland permit), will be somewhat uncertain. This uncertainty may be related to:

- Assumptions and subsequent estimate of baseline conditions (impingement and entrainment losses);

- Modeling assumptions and subsequent estimates of productivity of the environmental enhancement;

- Assumptions and subsequent predictions of stocking success;

- Assumptions regarding availability and productivity of newly accessible spawning, nursery, and foraging habitats resulting from fish passage restoration;

- Assumptions regarding the anticipated length of time for a restoration project to reach a given level of effectiveness.

Because of such uncertainties, restoration projects are often scaled to a level greater than that estimated to exactly offset impacted biota. For example, wetland replacement projects regulated by the U.S. Army Corps of Engineers are often required to have replacement ratios greater than 1:1 (i.e., more than one acre of replacement wetland for every acre of wetland destroyed) (USACE 2001). A study of Indiana wetland compensatory mitigation projects found average wetland replacement ratios to range from 1:1 for open water wetlands up to 7.6:1 for wet meadow wetlands (Robb 2001).

Such safety factors have been used in numerous restoration projects that were developed to mitigate CWIS operational losses at power plants. For example, at the PSEG's Salem Generating Station, 2,424 acres of restored marsh was estimated to be needed to replace the biomass of bay anchovy lost due to impingement and entrainment. Because of uncertainties and variability surrounding the fish production estimates for restored wetlands and other assumptions used to derive that acreage, a "safety factor" of about four was used to achieve consensus among stakeholders, increasing the restoration acreage to 10,000 acres.

The USEPA has concerns regarding the uncertainties associated with restoration success (USEPA 2003). Consequently, the USEPA is now considering requiring documentation of the sources and magnitude of uncertainty in restoration project performance as part of restoration proposals submitted to the permitting authority. The USEPA believes that a clear and thorough documentation of the sources and nature of uncertainty is vital to fully evaluating the ability of a project to meet its objectives and subsequently taking, as necessary, the appropriate steps to prevent or compensate for potential performance shortfalls. The USEPA believes that documentation of uncertainty must be quantitative wherever possible, qualitative otherwise, and make use of sound statistical techniques. Because of the complexity and evolving nature of restoration projects as an environmental management tool, most such projects will have several areas of uncertainty in descriptions of their anticipated performance. The USEPA is soliciting information on uncertainty in restoration projects and on appropriate methods for its characterization; the USEPA may include specific language regarding review and documentation of uncertainty in the final rule, which will be issued by February 16, 2004.

## 4.3 Monitoring

Because of the time lags typically encountered when measuring ecological responses to specific actions, activities, or environmental changes, difficulty in collecting data on natural systems, and confounding factors such as variable climatic conditions and unexpected anthropogenic influences, it is often difficult to determine the long-term effects of an environmental change, whether positive or negative (Wieringa and Morton 1996). Therefore, effective monitoring can be useful for evaluating both the short-term and long-term success of a restoration program. Monitoring is a meaningful way to document the performance of an environmental enhancement or overall CWIS mitigation program and is essential for validation of design criteria and for adaptive management.

Regardless of the type of restoration project selected, some type of monitoring should be considered to demonstrate that project goals and benefits are being, or have been, achieved. Monitoring plans should (1) identify the habitat features required for project success; (2) identify appropriate performance criteria; (3) establish a monitoring schedule; (4) identify the appropriate duration of monitoring; (5) establish criteria that trigger early corrective actions; and (6) develop alternative actions in the event that the project, as planned, becomes impossible or impracticable to complete because of unexpected or uncontrollable circumstances (Duke Energy 2002).

## 4.4 Adaptive Management

Adaptive management (as a component of the monitoring plan) should be considered as a component of many mitigation projects. Some types of mitigation (e.g., stocking programs) may not require an adaptive management approach if actions have been clearly agreed upon in advance. Reasons for using adaptive management include complications in linking specific management practices with resource responses, difficulty in scientifically measuring resource responses in the field, time lags between implementing mitigation activities and eliciting measurable resource responses, the complex and only partially understood interrelationships among many natural resources, and the confounding responses of resources to natural variability or cycles (Wieringa and Morton 1996, ISAB 2000). Adaptive management provides a mechanism to modify enhancement or restoration efforts in light of new information and other emerging aquatic resource issues (Atlantic States Marine Fisheries Commission 1999, USEPA 2003).

Adaptive management uses best available information or professional judgment when making decisions regarding how best to accomplish project goals, and allows those decisions to be revisited and revised as new information is collected (through monitoring and advances in restoration science) (Wieringa and Morton 1996). In some cases, it may be desirable to develop specific performance measures that serve as triggers for altering management actions associated with enhancement projects. The adaptive management program should also consider how the restoration program will be enforced through permit conditions or other measures and evaluate cost estimates and any enforceable payment schedules that may be part of the restoration project (Duke Energy 2002).

The USEPA has noted its interest in the adaptive management approach as a requirement in restoration proposals (USEPA 2003). The USEPA believes that under adaptive management, an approach is chosen to address a problem, and its effectiveness is monitored during its implementation. Information from this monitoring (as noted above) is then used to make adjustments, as necessary, to the approach. The USEPA believes that adaptive management is a particularly useful method when the outcome of a chosen approach is uncertain, as discussed in the previous section. Because of the uncertainty and evolving nature of restoration projects as an environmental management tool, the USEPA is considering requiring permittees who choose to utilize restoration projects to create and implement an adaptive management plan. The plan would outline, to the extent possible, the actions a permittee would take should monitoring of project performance indicate deviation of performance from acceptable levels. The plan would describe, quantitatively where possible, the performance levels at which project adjustment would be necessary (USEPA 2003).

The USEPA is also considering requiring that permittees stipulate performance measurement methods and metrics in the monitoring plan of their restoration proposal (USEPA 2003). The USEPA believes that the adaptive management process relies heavily on adequate performance measurement methods and metrics to alert project managers to project deviations from expected performance levels or to indicate that a project is meeting performance goals. It is important for these reasons that project planners choose performance metrics that reflect attainment of project goals. Consideration should also be given to allowing the use of alternative performance measures that can be implemented if it is later determined that primary measurement methods or metrics are unreliable. Thus, there will be a need to translate the language of the rule (i.e., maintain fish and shellfish in the water body, including the community structure and function, at “a comparable” or “substantially similar level to” that which would be achieved by meeting the impingement mortality and, when applicable, entrainment reduction requirements [USEPA 2002]) to quantitative measures as accurately and directly as possible. Proxy measurement methods should be used with adequate caution. The USEPA also believes that project planners should, where feasible, monitor for information useful for making corrections, as needed, in a project’s performance.

# 5
# SUMMARY AND CONCLUSIONS

This interim report evaluated five environmental enhancement approaches for potential use in mitigating impingement and entrainment impacts at CWISs. These approaches included (1) wetlands creation, restoration, and banking; (2) establishment or restoration of SAV; (3) construction of artificial habitats (particularly reefs); (4) restoration of fish passage; (5) supplementation of fish stocks through stocking; and (6) habitat protection. Each of these enhancement techniques has been successfully used in freshwater, estuarine, and marine habitats throughout the United States. These approaches are currently being implemented by various federal, state, and local government agencies, private organizations, and public and private partnerships to mitigate impacts to aquatic resources from a variety of anthropogenic causes, such as encroachment and pollution releases. Each of these enhancement approaches is based on underlying widely accepted ecological principles, and some may be considered as distinct subdisciplines of fisheries science. Scientific research to investigate and strengthen each of these approaches is ongoing.

Each of the enhancement approaches evaluated in this report may be applicable to mitigating operational impacts of CWISs. These approaches may be ecologically more beneficial and potentially more cost effective than modifying existing generating facilities with closed-cycle cooling systems or other engineering or operational modifications. Enhancement approaches involving the creation or restoration of wetlands and SAV and the construction of artificial habitats have the potential to offset CWIS impacts by increasing or enhancing spawning, foraging, and nursery habitats for target (and nontarget) fishes and invertebrates in freshwater, estuarine, and marine environments. The restoration of fish passage also has the potential to increase production by increasing access to existing historically available habitat that became inaccessible because of some form of anthropogenic stream obstruction (such as a dam or culvert). Fish passage restoration is most often used in riverine environments, although it is also being used to restore fish access to wetlands cut off by dikes and levees from estuarine and coastal areas. In addition to increasing numbers of fish, emigrating juveniles may provide important forage for piscivores that are lost due to CWIS operations. Stocking can be used to enhance specific fish stocks that are being impacted by impingement or entrainment. Fish stocking is widely used to restore, supplement, or establish fish species in a variety of aquatic habitats. Habitat protection may involve the direct purchase and management of existing quality habitat by an energy company, or may consist of a partnership between an energy company and a governmental or private organization or citizens group that identifies, purchases, and manages habitats for protection.

Each enhancement approach evaluated in this interim report is applicable to mitigating CWIS operational impacts and may be possible to implement as an enhancement approach that can target a particular species of concern (i.e., the species being affected by CWIS operations).

Depending on the species impacted by CWIS operations and on the local or regional environmental setting of the CWIS, it may not always be possible to implement an enhancement approach at a location where it can directly benefit the populations affected by impingement or entrainment. In such cases, direct mitigation may not be possible and benefits resulting from the enhancement would be incurred by ecological resources only marginally affected, if affected at all, by CWIS operations.

Environmental enhancements may provide additional long-term environmental benefits (e.g., flood control, habitat for wildlife, pollution reduction, and recreation) that would not be provided by technological and operational measures focused solely on reducing CWIS impacts. Such benefits would continue well after cessation of power plant operations.

Regardless of the environmental enhancement that might be considered at a site, a major factor that needs to be addressed is what level of an enhancement is necessary to mitigate for a specific level of impingement or entrainment. This question will be especially difficult to answer for enhancements that address impingement and entrainment impacts through increasing habitat availability and for enhancements that will benefit resources other than those experiencing impingement or entrainment impacts.

A four-step framework was identified to aid in the selection and scaling of restoration projects to mitigate CWIS impacts.  Steps in this framework may include: (1) setting the baseline, which determines the type and amount of resources that incur impingement and entrainment impacts and for which mitigation is needed; (2) consideration of technological and/or operational alternatives; (3) selecting the restoration approach; and (4) scaling the restoration project. Critical components of this framework include the need for early and frequent discussions with regulators, natural resource agencies, and appropriate stakeholders; a cost-benefit analysis of potential technological and/or operational mitigation alternatives; and the need to use one or more metrics linking impingement and entrainment impacts to one or more environmental enhancements and then scale the restoration projects to meet the needed mitigation level.

Future research on the applicability of environmental enhancements for mitigating CWIS impacts should focus on (1) increasing our understanding of the underlying science for successful enhancement, (2) continued development of implementation tools and monitoring approaches (including success criteria), and (3) continued development of methods for translating CWIS impacts into enhancement levels (scaling) that could achieve appropriate levels of mitigation.

In addition to the use of environmental enhancements for mitigating CWIS operational impacts, the USEPA has endorsed water quality trading through a recently released trading policy. This new policy, in conjunction with the USEPA's discussion of trading in its April 2002 proposed Section 316(b) regulations, indicates that the time is ripe for exploring new opportunities for trading. In its Section 316(b) proposal for existing facilities, the USEPA discusses trades of fish for fish; this report also describes the concept of trading pollutants for fish. These types of trades have never been employed; therefore, many issues must be carefully considered and policies developed to implement Section 316(b) trading. Some of the issues that will need further study include (1) determining the spatial scale in which trading partners must be located, (2) quantifying the units for trading (how many credits does a seller get for its excess performance and how many credits must a buyer purchase to meet its targets), (3) developing a common currency for trading (how to evaluate the improved environmental performance associated with a particular type of action), (4) determining and assigning compliance liability to the buyer and seller in a trade, and (5) educating regulators and other stakeholders to build their comfort with the concept of trading.

# 6
# REFERENCES

Able, K.W., D. M. Nemerson, P.R. Light and R.O. Bush. 2000. “Initial Response of Fishes to Marsh Restoration at a Former Salt Hay Farm Bordering Delaware Bay.” Pages 749-773 *in: Concepts and Controversies in Tidal Marsh Ecology*. M. P. Weinstein and D. A. Kreeger (eds.). Kluwer Academic Publishers, The Netherlands.

Able, K.W., D. Nemerson, R. Bush and P. Light 2001. “Spatial Variation in Delaware Bay (U.S.A.) Marsh Creek Fish Assemblages.” *Estuaries* 24(3):441-452.

Adam, P. 1990. *Saltmarsh Ecology*. Cambridge University Press, Cambridge, England, 461 p.

Adamus, P., and L. Stockwell. 1983, *A Method for Wetland Functional Assessment*. Report No. FHWA –IP-82-23, Offices of Research, Development and Technology, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Adamus, P., L. Stockwell, E. Clairain, M. Morrow, L. Rozas, R.D. Smith. 1991. *Wetland Evaluation Technique*. Wetlands Research Program Technical Report WRP-DE-2, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Admiraal, A., M. Morris, T. Brooks, J. Olson, and M. Miller. 1997. *Illinois Wetland Restoration and Creation Guide*. Illinois Natural History Survey Special Publication 19.

AFS – see American Fisheries Society.

Alliance for the Chesapeake Bay. 1994. “Record Shad Return Reported in the Susquehanna.” *Bay Journal* 4(4) July-Aug. Available at: http://www.bayjournal.com/94-08/shad.htm.

Alliance for the Chesapeake Bay. 1997. “Susquehanna Marks Record Number of American Shad.” *Bay Journal* 7(5) July-Aug. Available at: http://www.bayjournal.com/97-08/shad.htm.

Alliance for the Chesapeake Bay. 1998. “Record 30 Million American Shad Fry Released in Bay Tributaries.” *Bay Journal* 8(5) July-Aug. Available at: http://www.bayjournal.com/98-07/SHAD.htm.

Alliance for the Chesapeake Bay. 2000. “Shad Stocking Efforts in Bay Tributaries Starting to Show Results.” *Bay Journal* 10(6) Sept. Available at: http://www.bayjournal.com/00-09/shadside.htm.

Amaral, S.V., G.N. Garnett, and N. Taft. 1998. *Review of Downstream Fish Passage and Protection Technology Evaluations and Effectiveness*. Report TR-111517. Electric Power Research Institute, Palo Alto, CA.

Amaral, S.V., E.P. Taft, F.C. Winchell, A. Plizga, E. Paolini, and C.W. Sullivan. 1999. "Fish Diversion Effectiveness of a Modular Inclined Screen System." Pages 61-78 *in*: *Innovations in Fish Passage Technology*, M. Odeh (ed.). American Fisheries Society, Bethesda, MD.

Ambrose, R.F., and S.L. Swarbrick. 1989. "Comparison of Fish Assemblages on Artificial and Natural Reefs off the Coast of Southern California." *Bulletin Marine Science* 44(2):718-733.

Ambrose, R.F. 1994a. "Mitigating the Effects of a Coastal Power Plant on a Kelp Forest Community: Rationale and Requirements for an Artificial Reef." *Bulletin of Marine Science* 55(2-3):694-708.

Ambrose, R.F. 1994b. *Resource Replacement Alternatives Involving Constructed Reefs in Southern California.* Unpublished report. Sept. Available at: http://www.darcnw.noaa.gov/montrose/2001.pdf]

American Fisheries Society. 1992. *Investigation and Valuation of Fish Kills*. American Fisheries Society Special Publication No. 24. Pollution Committee, Southern Division, and the Socioeconomic Section, American Fisheries Society, Bethesda, MD.

American Fisheries Society. 2000. *Guidelines for Evaluating Fish Passage Technologies*. Bioengineering Section, American Fisheries Society. Available at: http://biosys.bre.orst.edu/afseng/news.htm#passage_comm.

American Rivers. 2002. *Dam Removal Costs*. Available at: http://www.amrivers.org/damremovaltoolkit/damremovalcosts.htm.

American Rivers, Friends of the Earth, and Trout Unlimited. 1999. *Dam Removal Success Stories: Restoring Rivers through Selective Removal of Dams that Don't Make Sense*. Available at: http://www.amrivers.org/damremovaltoolkit/successstoriesreport.htm.

American Society of Civil Engineers. 1997. *Guidelines for Retirement of Dams and Hydroelectric Facilities*. American Society of Civil Engineers, Reston, VA.

Arnold, J.G., P.M. Allen, and D.S. Morgan. 2001. "Hydrologic Model for Design and Constructed Wetlands." *Wetlands* 21(2):167-178.

Aronson, J., S. Dhillion, and LeFloc'h. 1996. "On the Need to Select an Ecosystem of Reference, However Imperfect: A Reply to Pickett and Parker." *Restoration Ecology* 3:1-3.

Atlantic States Marine Fisheries Commission. 1997. *Submerged Aquatic Vegetation Policy*. ASMFC Habitat Management Series #3.

Atlantic States Marine Fisheries Commission. 1999. *Amendment 1 to the Interstate Fishery Management Plan for Shad and River Herring*. Fishery Management Report No. 35. Marine Fisheries Commission, Washington, DC. April.

Atlantic States Marine Fisheries Commission. 2000. *Evaluating Fishing Gear Impacts to Submerged Aquatic Vegetation and Determining Mitigation Strategies*. ASMFC Habitat Management Series #5.

Atlantic and Gulf States Marine Fisheries Commissions. 1998. *Coastal Artificial Reef Planning Guide*. Prepared by the Joint Artificial Reef Technical Committee, Atlantic and Gulf States Marine Fisheries Commissions. Dec. Available at: http://www.gsmfc.org/pubs/SFRP/Coastal_Artificial_Reef_Planning_Guide_1998.pdf]

ASCE – see American Society of Civil Engineers.

Ayvazian, S.G., L.A. Deegan, and J.T. Finn. 1992. "Comparison of Habitat Use by Estuarine Fish Assemblages in the Acadian and Virginian Zoogeographic Provinces." *Estuaries* 15:368-383.

Bailey, D.E., J.J. Loos, E.S. Perry, and R.J. Wood. 2000. "A Retrospective Evaluation of 316(B) Mitigation Options Using a Decision Analysis Framework." *Environmental Science and Policy* 3:S25-S36.

Baine, M. 2001. "Artificial Reefs: A Review of Their Design, Application, Management, and Performance." *Ocean and Coastal Management* 44:241-259.

Baish, S.K., S.D. David, and W.L. Graf. 2002. "The Complex Decisionmaking Process for Removing Dams." *Environment* 44(4):21-31.

Bakker, J.P., P. Esselink, K.S. Dijkema, W.E. van Duin, and D.J. de Jong. 2002. "Restoration of Salt Marshes in the Netherlands." *Hydrobiologia* 478:29-51.

Baltz, D.M., C. Rakocinski, and J.W. Fleeger. 1993. "Microhabitat Use by Marsh-Edge Fishes in a Louisiana Estuary. *Environmental Biology of Fishes* 36:109-126.

Barbier, E.B., M. Acreman, and D. Knowler. 1997. *Economic Valuation of Wetlands: A Guide for Policy Makers and Planners*. Ramsar Convention Bureau, Gland, Switzerland.

Barnett, A.M., T.D. Johnson, and R. Appy. 1991. "Evaluation of the Mitigative Value of an Artificial Reef Relative to Open Coast Sand Bottom by the Biological Evaluation Standardized Techniques (BEST)." Pages 231-237 *in: Recent Advances in Aquatic Habitat Technology*. Proceedings of the Japan-U.S. Symposium on Artificial Habitat for Fisheries. M. Nakamura, R.S. Grove, and C.J. Sonu (eds.).

Bates, P.E. 1999. *Fish Passage Design at Culverts, a Manual for Fish Passage at Road Crossings*. Washington Department of Fish and Wildlife, Olympia, WA.

Beck, M.W., K.L. Heck, K.W. Able, D.L. Childers, D.B. Eggleston, B.M. Gillanders, B. Halpern, C.G. Hays, K. Hoshino, T.J. Minello, R.J. Orth, P.F. Sheridan, and M.P. Weinstein. 2001. "The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates." *BioScience* 51(8)633-641.

Blackett, R.F. 1987. "Development and Performance of an Alaskan Steeppass Fishway for Sockeye Salmon (*Oncorhynchus nerka*)." *Can. J. Aquat. Sci.* 44:66-76.

Blama, R., M. Landin, S Maynord, and J. Gill. 1995. "Eastern Neck National Wildlife Refuge Salt Marsh: Innovative Structures and Bioengineering." *National Interagency Workshop on Wetlands*, 5-7 April, New Orleans, LA.

Blankenship, K., 1999. "Return of Spawning Shad a Tribute to Stocking, Passages." *Bay Journal* 9(5) July-Aug. Available at: http://www.bayjournal.com/99-07/SHAD.htm.

Blankenship, K., 2001. "Strong Shad Runs Reported in Bay's Tributaries." *Bay Journal* 11(6) Sept. Available at: http://www.bayjournal.com/01-09/shad.htm.

Boesch, D.F., and R.E. Turner. 1984. "Dependence of Fishery Species on Salt Marshes: The Role of Food and Refuge." *Estuaries* 7:460-468.

Bohlen, C., T Grasso, M. Hirshfield, B. Kooser, A. Powers, J. Watts, and E. Zucker. 1994. *Wetlands Permitting Programs in the Chesapeake Bay Area*. Chesapeake Bay Foundation.

Brady, V.J., B.J. Cardinale, J.P. Gathman, and T.M. Burton. 2002. "Does Facilitation of Faunal Recruitment Benefit Ecosystem Restoration? An Experimental Study of Invertebrate Assemblages in Wetland Mesocosms." *Restoration Ecology* 10(4):617-626.

Brinson, M., 1993, *A Hydrogeomorphic Classification for Wetlands*. Wetlands Research Program Technical Report WRP-DE-4, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Brown, S.C., and P.L.M. Veneman. 2001. "Effectiveness of Compensatory Wetland Mitigation in Massachusetts, USA." *Wetlands* 21(4):508-518.

Bunt, C.M. 2001. "Fishway Entrance Modifications Enhance Fish Attraction." *Fisheries Management and Ecology* 8(2):95-105.

Bunt, C.M., C. Katopodis, and R.S. McKinley. 1999. "Attraction and Passage Efficiency of White Suckers and Smallmouth Bass by Two Denil Fishways." *North American Journal of Fisheries Management* 19(3):793-803.

Bureau of Fisheries Management and Habitat Protection. 1999. *An Evaluation of Stocking Strategies in Wisconsin with an Analysis of Projected Stocking Needs*. Prepared by Wisconsin Department of Natural Resources, Bureau of Fisheries Management and Habitat Protection, for the Joint Legislative Audit Committee, Madison, WI, April.

Cada, G.F., and M.J. Sale. 1993. "Status of Fish Passage Facilities at Nonfederal Hydropower Projects." *Fisheries* 18(7):4-12.

California Coastal Commission. 2001. *SONGS Mitigation Program: 2002 and 2003 Two-Year Work Program and Budget.* Energy and Ocean Resources Report W-14. Nov. 21.

California Regional Water Control Board. 2003. *Administrative Draft, Waste Discharge Requirements Order No. R3-2003-0001, NPDES No. CA0050598 for Duke Energy North America, Morro Bay Power Plant, Units 1 and 2, San Luis Obispo County*.

Callaway, J.C. 2001. "Hydrology and Substrate." Chapter 3 *in: Handbook for Restoring Tidal Wetlands*. J. Zedler (ed.). CRC Press, Boca Rotan, FL.

Campbell, D.A., C.A. Cole and R.P. Brooks. 2002. "A Comparison of Created and Natural Wetlands in Pennsylvania, USA." *Wetlands Ecology and Management* 10:41-49.

Carr M.H, and M.A Hixon. 1995. "Predation Effects on Early Post-Settlement Survivorship of Coral-Reef Fishes." *Marine Ecology Progress Series* 124:31-42.

Carter, J.W., A.L. Carpenter, M.S. Foster, and W.N. Jessee. 1985a. "Benthic Succession on an Artificial Reef Designed to Support a Kelp-Reef Community." *Bulletin of Marine Science* 37(1):86-113.

Carter, J.W., W.N. Jessee, M.S. Foster, and A.L. Carpenter. 1985b. "Management of Artificial Reefs Designed to Support Natural Communities." *Bulletin of Marine Science* 37(1):114-128.

CCC – see California Coastal Commission.

CDEP – see Connecticut Department of Environmental Protection.

Charbonnel, E., C. Serre, S. Ruitton, J.-G. Harmelin, and A. Jensen. 2002. "Effects of Increased Habitat Complexity on Fish Assemblages Associated with Large Artificial Reef Units (French Mediterranean Coast)." *ICES J. Marine Science* 59:S208-S213.

Cheney, D., R. Oestman, G. Volkhardt, and J. Getz. 1994. "Creation of Rocky Intertidal Habitats to Mitigate for the Construction of a Large Marina in Puget Sound, Washington." *Bulletin of Marine Science* 55(2-3):772-782.

Chesapeake Bay Program. 1999. *Fish Passage Annual Report*. Available at www.chesapeakebay.net/fishpass.htm.

Chesapeake Bay Program. 2000. *Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis*. Chesapeake Bay Program, Annapolis, MD.

Chesapeake Bay Restoration Program. 2002a. *Fish Passage Restoration*. Available at: http://www.chesapeakebay.net/restrtn.htm.

Chesapeake Bay Program. 2002b. *Little Falls Dam Fishway Project*. Available at www.chesapeakebay.net/info/littlefall.html.

Clay, C.H. 1995. *Design of Fishways and Other Fish Facilities.* 2nd Edition. Lewis Publishers, Boca Raton, FL.

Coastal America. 1999. *Project Summary, Little Falls Dam Passage Project*. Washington, DC. Fact sheet available at: http://www.coastalamerica.gov/text/regions/ma/lfallsdam.html.

Costa-Pierce, B.A., and M.P. Weinstein. 2002. "Use of Dredge Materials for Coastal Restoration." *Ecological Engineering*. 19:181-186.

Coll, J., J. Moranta, O. Reñones, A. García-Rubies, and I. Moreno. 1998. "Influence of Substrate and Deployment Time on Fish Assemblages on an Artificial Reef at Formentera Island (Balearic Islands, Western Mediterranean)." *Hydrobiologia* 385:139-152.

Collins, M.R., T.I.J. Smith, W.E. Jenkins, and M.R. Denson. 2002. "Small Marine Reserves May Increase Escapement of Red Drum." *Fisheries* 27(2):20-24.

Colorado River Endangered Fish Recovery Program. 2002. *Endangered Colorado River Basin Fish – Colorado Pike Minnow, Fact Sheet*. U.S. Fish and Wildlife Service, Lakewood, CO. Available at http://www.r6.fws.gov/coloradoriver/Crcsq.htm

Connecticut Department of Environmental Protection. 2002. *Detailed Description of Connecticut's Fisheries Program*. Available at: www.dep.state.ct.us/burnatr/fishing/geninfo/progrms.htm.

Conservation Fund. 2001. *2001 Annual Report*. Available at: http://www.conservationfund.org/pdf/2001%20annual%20report/2001%20annual%20report.pdf.

Costa-Pierce, B.A., and M.P. Weinstein. 2002. "Use of Dredge Materials for Coastal Restoration." *Ecological Engineering* 19:181-186.

Craft, C., J. Reader, J.N. Sacco, and S.W. Bromme. 1999. "Twenty-five Years of Ecosystem Development of Constructed *Spartina alterniflora* (Loisel) Marshes." *Ecological Applications* 9(4):1405-1419.

Craft, C., S. Broome, and C. Campbell. 2002. “Fifteen Years of Vegetation and Soil Development after Brackish-Water Marsh Creation.” *Restoration Ecology* 10(2):248-258.

CREFRP – see Colorado River Endangered Fish Recovery Program.

Daiber, F.C. 1977. “Salt Marsh Animals: Distributions Related to Tidal Flooding, Salinity, and Vegetation.” Chapter 5, pp. 79-108 *in: Wet Coastal Ecosystems*. V.J. Chapman (ed.). Elsevier Scientific Publishing Co., Amsterdam, The Netherlands.

Dame, R.F., E. Koepfler, and L. Gregory. 2000. “Benthic-Pelagic Coupling in Marsh-Estuarine Ecosystems.” *In: Concepts and Controversies in Tidal Mash Ecology*. M.P. Weinstein and D.A. Kreeger (eds.). Kluwer Academic Publishers, Norwell, MA.

Davis, G.E. 1985. “Artificial Structures to Mitigate Marina Construction Impacts on Spiny Lobster, *Panulirus argus*.” *Bulletin of Marine Science* 37(1):151-156.

Deegan, L., J. Hughes, and R. Rountree. 2000. “Salt Marsh Ecosystem Support of Marine Transient Species.” *In: Concepts and Controversies in Tidal Marsh Ecology*. M. Weinstein and D. Kreeger (eds.). Kluwer Academic Publishers, Norwell, MA.

DeMartini, E.E., A.M. Barnett, T.D. Johnson, and R.F. Ambrose. 1994. “Growth and Production Estimates for Biomass-Dominant Fishes on a Southern California Artificial Reef.” *Bulletin of Marine Science* 55(2-3):484-500.

Demgen, F.C. 1988. “A Review of Eighteen Wetland Mitigation Sites in the San Francisco Bay Region.” Pages 318-322 *in: Urban Wetlands*. Proceedings of the National Wetland Symposium. Oakland, CA.

Department of Defense et al. 1997. “The National Action Plan to Implement the Hydrogeomorphic Approach to Assessing Wetland Functions.” *Federal Register* Vol. 62, No. 119, pp. 33607-33620, June 20.

Department of the Army. 2002. *Guidelines on the Establishment and Operation of Wetland Mitigation Banks in Georgia*. Department of the Army, Savannah District; U.S. Environmental Protection Agency, Region IV; U.S. Fish and Wildlife Service, Southeast Region; and Georgia Department of Natural Resources.

Desmond, J.S., D.H. Deutschman, and J.B. Zedler. 2002. “Spatial and Temporal Variation in Estuarine and Invertebrate Assemblages: Analysis of an 11-Year Data Set.” *Estuaries* 25(4A):552-569.

Dey, W., S. Jinks, and W. Van Winkle. 2002. *Evaluating the Effects of Power Plant Operations on Aquatic Communities: A Ecological Risk Assessment Framework for Evaluating Adverse Environmental Impact Under CWA §316(b)*. EPRI Report 1000758. Electric Power Research Institute, Palo Alto, CA.

Dey, W.P. 2003. "Use of Equivalent Loss Models under Section 316(b) of the Clean Water Act." Pages 264-290 *in:* D. Dixon, J.A. Veil, and J. Wisniewski (Eds.), *Defining and Assessing Adverse Environmental Impact from Power Plant Impingement and Entrainment of Aquatic Organisms*. A.A. Balkema Publishers, The Netherlands.

Deysher, L.E., T.A. Dean, R.S. Grove, and A. Jahn. 2002. "Design Considerations for an Artificial Reef to Grow Giant Kelp (*Macrocystis pyrifera*) in Southern California." *ICES Journal of Marine Science* 59:S201-S207

Dixon, D.A., and J. Wisniewski. (eds.). 2002. *Defining and Assessing Adverse Environmental Impact Under Section 316(b) of the Clean Water Act*. The Scientific World Publishers, London.

DOA – see Department of the Army.

Duke Energy. 2002. *Duke Energy Morro Bay LLC, Morro Bay Power Plant Modernization Project, Habitat Enhancement Program*. Morro Bay, CA.

EARRN – see European Artificial Reef Research Network.

Edwards, W.J., L. Babcock-Jackson, and D.A. Culver. 2000. "Prevention of the Spread of Zebra Mussels during Fish Hatchery and Aquaculture Activities." *North American Journal of Aquaculture* 62(3):229-236.

Electric Power Research Institute. 1999. *Catalog of Assessment Methods for Evaluating the Effects of Power Plant Operations on Aquatic Communities*. Report TR-112013. Palo Alto, CA.

Electric Power Research Institute. 2000. *Review of Entrainment Survival Studies: 1970-2000*. Prepared for Electric Power Research Institute, Inc., by EA Engineering Science and Technology.

Electric Power Research Institute. 2001. *Evaluating the Effects of Power Plant Operating on Aquatic Communities: An Ecological Risk Assessment Framework for Evaluating Adverse Environmental Impact Under CWA §316(b)*. EPRI Report 1000758. Palo Alto, CA.

Electric Power Research Institute. 2002. *Evaluating the Effects of Power Plants on Aquatic Communities: Guidelines for Selection of Assessment Methods*. EPRI Report 1005176. Palo Alto, CA.

Electric Power Research Institute. 2003. *Evaluating the Effects of Power Plant Operations on Aquatic Communities: Summary of Impingement Survival Studies*. EPRI Report 1007821. Palo Alto, CA.

Elizinga, C., D. Salzer, and J. Willoughby. 1998. *Measuring & Monitoring Plant Populations*. BLM Technical Reference 1730-1, BLM/RS/ST-98/005+1730. National Applied Resource Sciences Center, Bureau of Land Management, Denver, CO.

Epifanio, J. 2000. “The Status of Coldwater Fishery Management in the United States: An Overview of State Programs.” *Fisheries* 25(7): 13-27.

EPRI – see Electric Power Research Institute.

European Artificial Reef Research Network. 1999. *Bibliography of Artificial Reef Research*. Available at http://www.soes.soton.ac.uk/research/groups/EARRN/. Sept. 1.

Federal Interagency Stream Restoration Working Group. 1998. *Stream Corridor Restoration, Principles, Processes, and Practices*. GPO Item No. 0120-A.

Feierabend, S.J., and J.M. Zelanzy. 1987. *Status Report on Our Nation’s Wetlands*. National Wildlife Federation, Washington, D.C. 50 p.

Fell, P.E., R.S. Warren, and W.A. Niering. 2000. “Restoration of Salt and Brackish Tidelands in Southern New England.” Pages 845-858 *in: Concepts and Controversies in Tidal Marsh Ecology*, M.P. Weinstein and D.A. Kreeger (eds.). Kluwer Academic Publishers, Norwell, MA.

Felton, S.P., R. Grace, and M. Landolt. 1994. “Significantly Higher Levels of Zinc and Copper Found in Wild Compared to Hatchery-Reared Coho Salmon Smolts *Oncorhynchus Kisutch*.” *Diseases of Aquatic Organisms* 18(3):233-236.

Fernandez, L., and L. Karp. 1998. “Restoring Wetlands Through Wetlands Mitigation Banks.” *Environmental and Resource Economics* 12:323-344.

FISRWG – see Federal Interagency Stream Restoration Working Group.

Flagg, T.A., B.A. Berejikian, J.E. Colt, W.W. Dickhoff, L.W. Harrell, D.J. Maynard, C.E. Nash, M.S. Strom, R.N. Iwamoto, and C.V.W. Mahnken. 2000. *Ecological and Behavioral Impacts of Artificial Production Strategies on the Abundance of Wild Salmon Populations. A Review of Practices in the Pacific Northwest.* NOAA Technical Memorandum NMFS-NWFSC-41. National Marine Fisheries Service, Northwest Fisheries Science Center, Resource Enhancement and Utilization Technologies, Seattle, WA. Available at: http://www.nwfsc.noaa.gov/pubs/tm/tm41/tm41/tm41.pdf.

Fleming, I.A., and M.R. Gross. 1992. “Reproductive Behavior of Hatchery and Wild Coho Salmon *(Oncorhynchus kisutch)*–Does It Differ?” *Aquaculture* 103(2):101-121.

Flosi, G., S. Downie, J. Hopelain, M. Bird, R. Coey, and B. Collins. 1998. *California Salmonid Stream Habitat Restoration Manual*. 3rd Edition. California Department of Fish and Game, Inland Fisheries Division, Sacramento, CA.

Fonseca, M.S., W.J. Kenworthy, and G.W. Thayer. 1998. *Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters*. Decision Analysis Series No. 12. National Atmospheric and Atmospheric Administration, Coastal Ocean Program, Silver Spring, MD.

Foster, K.L., F.W. Steimle, W.C. Muir, R.K. Kropp, and B.E. Conlin. 1994. "Mitigation Potential of Habitat Replacement: Concrete Artificial Reef in Delaware Bay—Preliminary Results." *Bulletin of Marine Science* 55(2-3):783-795.

Francfort, J.E., G.F. Cada, D.D. Dauble, R.T. Hunt, D.W. Jones, B.N. Rinehart, G.L. Sommers, and R.J. Costello. 1994. *Environmental Mitigation at Hydroelectric Projects; Vol. II: Benefits and Costs of Fish Passage and Protection*. Prepared by Idaho National Engineering Laboratory, Idaho Falls, ID, for U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Washington, D.C.

Friant, S.L. 1996. "When Ecological Considerations Matter in the RI/FS Process." *DOE Risk Management* 6(1):2-3.

Funk, J.L., and J.W. Robinson. 1974. *Changes in the Channel of the Lower Missouri River and Effects on Fish and Wildlife.* Missouri Department of Conservation, Jefferson City, MO.

Garbarino, S., R. Blama, M. Landin, R. Hammerschlag, and S. Syphax. 1995. "Kenilworth Marsh: A Classic Wetland Restoration Success Story in the Nation's Capitol." *National Interagency Workshop on Wetlands*, 5-7 April, 1995, New Orleans, LA.

Giorgi, A., M. Miller, and J. Stevenson. 2002. *Mainstem Passage Strategies in the Columbia River System: Transportation, Spill, and Flow Augmentation*. Prepared by BioAnalysts, Inc., Boise, ID, for the Northwest Power Planning Council, Portland, OR.

Goodwin, P., A.J. Mehta, and J.B. Zedler. 2001. "Tidal Wetland Restoration: An Introduction." *Journal of Coastal Research*, Special Issue No. 27:1-6.

Goodyear, C.P. 1978. *Entrainment Impact Estimates Using the Equivalent Adult Approach*. Report No. FWS/OBS-78/65. U.S. Fish and Wildlife Service, Washington, D.C.

Gotceitas, V. 1990a. "Variation in Plant Stem Density and Its Effects on Foraging Success of Juvenile Bluegill Sunfish." *Environmental Biology of Fishes* 27:63-70.

Gotceitas, V. 1990b. "Foraging and Predator Avoidance: A Test of a Patch Choice Model with Juvenile Bluegill Sunfish." *Oecologia* 83:346-351.

Grossman, G.D., G.P. Jones, and W.J. Seaman, Jr. 1997. "Do artificial Reefs Increase Regional Fish Production? A Review of Existing Data." *Fisheries* 22(4):17-23.

Grove, R.S. 1982. “Artificial Reefs as a Resource Management Option for Siting Coastal Power Stations in Southern California.” *Marine Fisheries Review* 44(6-7):24-27.

Gulf States Marine Fisheries Commission. 1997. *Guidelines for Marine Artificial Reef Materials*. Artificial Reef Subcommittee, Technical Coordinating Committee, Gulf States Marine Fisheries Commission. Jan. Available at: http://www.gsmfc.org/pubs/SFRP/Guidelines_for_Marine_Artificial_Reef_Materials_January _1997.pdf.

Gunter, G. 1956. “Some Relations of Faunal Distribution to Salinity in Estuarine Waters.” *Ecology* 37:616-619.

Hampel, H., A. Cattrijsse, and M. Vincx. 2003. “Habitat Value of a Developing Estuarine Brackish Marsh for Fish and Macrocrustaceans.” *ICES Journal of Marine Science* 60:278-289.

Haney, A., and R.L. Power. 1996. “Adaptive Management for Sound Ecosystem Management.” *Environmental Management* 20:879-886.

Hanson, B. 1999. “Effectiveness of Two Surface Bypass Facilities on the Connecticut River to Pass Emigrating Atlantic Salmon Smolts.” Pages 43-59 *in*: *Innovations in Fish Passage Technology*. M. Odeh (ed.). American Fisheries Society, Bethesda, MD.

Haro, A., M. Odeh, T. Castro-Santos, and J.F. Noreika. 1999a. “Effect of Slope and Headpond on Passage of American Shad and Blueback Herring through Simple Denil and Deepend Alaska Steeppass Fishways.” *North American Journal of Fisheries Management* 19:51-58.

Haro, A., D. Deagan, J. Horne, B. Kulik, and J. Boubee. 1999b. *An Investigation of the Feasibility of Employing Hydroacoustic Monitoring as a Means to Detect the Presence and Movement of Large, Adult Eels* (*Genus* Anguilla). S.O. Conte Anadromous Fish Research Center Internal Report No. 99-01. Available at: http://www.lsc.usgs.gov/cafl/reports/haro.htm.

Hatchery Scientific Review Group. 2000. *Draft Scientific Framework for Artificial Propagation of Salmon and Steelhead*. Hatchery Scientific Review Group, Puget Sound and Coastal Washington Hatchery Reform Project, Seattle, WA. Sept.

Hatchery Scientific Review Group. 2002. *Hatchery Reform Recommendations*. Hatchery Scientific Review Group, Puget Sound and Coastal Washington Hatchery Reform Project, Seattle, WA. Feb.

Havens, K.J., L.M. Varnell, and B.D. Watts. 2002. “Maturation of a Constructed Tidal Marsh Relative to two Natural Reference Tidal Marshes over 12 Years.” *Ecological Engineering* 18:305-315.

Haynes, R.J., and L. Moore. 1988. “Reestablishment of Bottomland Hardwoods within National Wildlife Refuges in the Southwest.” Pages 95-103 *in: Increasing Our Wetland Resources.* J. Zelazny and J.J. S.J. Feierabend (eds.). Proc. Conf. Natl. Wildl. Fed., Washington, D.C.

Hayse, J.W., and T.E. Wissing. 1996. "Effects of Stem Density of Artificial Vegetation on Abundance and Growth of Age-0 Bluegills and Predation by Largemouth Bass." *Transactions of the American Fisheries Society* 125:422-433.

Heck, K.L., Jr., K.W. Able, M.P. Fahay, and C.T. Roman. 1989. "Fishes and Decapod Crustaceans of Cape Cod Eelgrass Meadows: Species Composition, Seasonal Abundance Patterns, and Comparison with Unvegetated Substrates." *Estuaries* 12:59-65.

Heidinger, R.C. 1993. "Chapter 13, Stocking for Sport Fisheries Enhancement." Pages 309-333 *in: Inland Fisheries Management in North America*. C.C. Kohler and W.A. Hubert (eds.). American Fisheries Society, Bethesda, MD.

Heinz Center. 2002. *Dam Removal, Science and Decision Making*. H. John Heinz III Center for Science, Economics and the Environment, Washington, D.C.

Hellawell, J.M. 1991. "Development of a Rationale for Monitoring." Pages 1-14 *in: Monitoring for Conservation and Ecology*. F.B. Goldsmith (ed.). Chapman and Hall, New York, NY.

Hendricks, M.L., R.L. Hoopes, D.A. Arnold, and M.L. Kaufmann. 2002. "Homing of Hatchery-Reared American Shad to the Lehigh River, a Tributary to the Delaware River." *North American Journal of Fisheries Management* 22(1)243-248.

Hilborn, R. 1992. "Hatcheries and the Future of Salmon in the Northwest." *Fisheries* 17(1):5-8.

Hobbs, R.J., and D.A. Norton. 1996. "Commentary: Towards a Conceptual Framework for Restoration Ecology." *Restoration Ecology* 4:93-110.

Holbrook, S.J., and R.J. Schmitt. 1988. "Effects of Predation Risk on Foraging Behavior: Mechanisms Altering Patch Choice." *Journal of Experimental Marine Biology and Ecology* 121:151-163.

Holling, C.S. 1978. "Adaptive Environmental Assessment and Management." Pages 1-139 *in: International Series on Applied Systems Analysis*. John Wiley, New York, NY.

Holt, G.J. 1993. "The Potential Role of Larval Fish Culture in Alleviating Population and Habitat Losses." *American Fisheries Society Symposium* 14:167-172.

Hughes, J.E., L.A. Deegan, J.C. Wyda, M.J. Weaver, and A. Wright. 2002. "The Effects of Eelgrass Habitat Loss on Estuarine Fish Communities of Southern New England." *Estuaries* 25(2):235-249.

Hurley, L.M. 1991. "Submerged Aquatic Vegetation." Pages 2-1 to 2-19 *in: Habitat Requirements for Chesapeake Bay Living Resources*. S.L. Funderburk, S.J. Jordan, J.A. Mihursky, and D. Riley (eds.). Living Resources Subcommittee, Habitat Objectives Workgroup, Chesapeake Research Consortium, Solomons, MD.

Independent Scientific Advisory Board. 2000. *Consistency of the Council's Artificial Production Policies and Implementation Strategies with Multi-Species Framework Principles and Scientific Review Team Guidelines*. ISAB APR Report No. 2. Independent Scientific Advisory Board, Northwest Power Planning Council, National Marine Fisheries Service, Portland, OR.

Interagency Workgroup on Wetland Restoration. Undated. *An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement*.

Iowa Department of Natural Resources. 2002. *Manchester Fish Hatchery*. Iowa Department of Natural Resources, Manchester, IA. Available at: http://www.state.ia.us/fish/programs/hatchery/manchest.htm.

ISAB – see Independent Scientific Advisory Board.

Iverson, T.K., J.E. Keister, and R.D. MacDonald. 1999. "Summary of the Evaluation of Fish Passage through Three Surface Spill Gate Designs at Rock Island Dam in 1996." Pages 129-142 *in*: *Innovations in Fish Passage Technology*. M. Odeh, (ed.). American Fisheries Society, Bethesda, MD.

James-Pirri, M.J., K.B. Raposa, and J.G. Catena. 2001. "Diet Composition of Mummichogs, *Fundulus heteroclitus*, from Restoring and Unrestricted Regions of a New England (U.S.A.) Salt Marsh." *Estuarine, Coastal and Shelf Science* 53: 205-213.

Janvrin, J. 2002. *Estimate of Habitat Restoration Costs for the Upper Mississippi River System*. Upper Mississippi River Conservation Committee, Rock Island, IL. Available at: http://www.mississippi-river.com/umrcc/pdf/AppendixA.pdf.

Jensen, A.L., R.H. Reider, and W.P. Kovalak. 1988. "Estimation of Production Foregone." *North American Journal of Fisheries Management* 8:191-198.

Joint Hatchery Review Committee. 2001. *Final Report on Anadromous Salmonid Fish Hatcheries in California*. California Department of Fish and Game, National Marine Fisheries Service Southwest Region, Joint Hatchery Review Committee. Dec. 3. Available at: http://dfg.ca.gov/lands/hacthery_review_report_2002.pdf.

Jones, D.R., J.W. Kiceniuk, and O.S. Bamford. 1974. "Evaluation of the Swimming Performance of Several Fish Species from the Mackenzie River." *Journal of the Fisheries Research Board of Canada* 31:1641-1647.

Jones, K.B. 1986. "Inventory and Monitoring Process." Pages 1-10 *in*: *Inventory and Monitoring of Wildlife Habitat*. A.Y. Cooperrider, R.J. Boyd, and H.R. Stuart (eds.). U.S. Department of Interior, Bureau of Land Management Service Center, Denver CO.

Johnson, T.D., A.M. Barnett, E.E. DeMartini, L.L. Craft, R.F. Ambrose, and L.J. Purcell. 1994. “Fish Production and Habitat Utilization on a Southern California Artificial Reef.” *Bulletin of Marine Science* 55(2-3):709-723.

Jorgensen, S.E., and W.J. Mitsch. 1989. “Classification and Examples of Ecological Engineering.” Chapter 2 *in: Ecological Engineering: An Introduction to Ecotechnology*. W.J. Mitsch and S.E. Jorgensen (eds.).

Kamula, R. 2001. *Flow Over Weirs with Application to Fish Passage Facilities*. Department of Process and Environmental Engineering, University of Oulu, Finland.

Kay, D. 2002. Personal communication from Kay (San Onofre Nuclear Generating Station, Southern California Edison) to Lina Urquidi (Argonne National Laboratory, Argonne, IL).

Kemp, W.M., P.A. Sampson, J. Tuttle, and W.R. Boynton. 1992. “Seasonal Depletion of Oxygen from Bottom Waters of Chesapeake Bay: Roles of Benthic and Planktonic Respiration and Physical Exchange Processes.” *Marine Ecology Progress Series* 85:137-152.

Kentula, M., R. Brooks, S. Gwin, C. Holland, A. Sherman, and J. Sifneos. 1992. *An Approach to Improving Decision Making in Wetland Restoration and Creation*. A. Hairston (ed.). U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR.

Kiesecker, J.M., A.R. Blaustein, and C.L. Miller. 2001. “Transfer of a Pathogen from Fish to Amphibians.” *Conservation Biology* 15(4):1064-1070.

King, D.M., and C.C. Bohlen. 1994. *Compensation Ratios for Wetland Mitigation*. CEES Working Paper UMCEES-CBL-94-10. University of Maryland, Center for Environmental and Estuarine Studies, Chesapeake Biological Laboratory, Solomons, MD.

Kneib, R.T. 1987. “Predation Risk and Use of Intertidal Habitats by Young Fishes and Shrimp.” *Ecology* 68(2):379-386.

Kneib, R.T. 1997. “The Role of Tidal Marshes in the Ecology of Estuarine Nekton.” Pages 163-220 *in: Oceanography and Marine Biology: an Annual Review 1997*. A.D. Ansell, R.N. Gibson, and Margaret Barnes (eds.). UCL Press.

Knotek, W.L., M. Deleray, and B. Marotz. 1997. *Hungry Horse Dam Fisheries Mitigation Program, Fish Passage and Habitat Improvement in the Upper Flathead River Basin*. Report DOE/BP-60559-4. Prepared by Montana Department of Fish, Wildlife, and Parks, Helena, MT, for U.S. Department of Energy, Bonneville Power Administration, Portland, OR.

Kohler, C.C., and W.A. Hubert (eds.). 1993. *Inland Fisheries Management in North America*. American Fisheries Society, Bethesda, MD.

Kruczyaski, W.L. 1990. "Options To Be Considered in Preparation and Evolution of Mitigation Plans." Pages 555-570 *in*: *Wetland Creation and Restoration, the Status of the Science*. J.A. Kusler and M.E. Kentula (eds.). Island Press, Washington, D.C.

Kusler, J.A., and M.E. Kentula. 1989a. *Wetland Creation and Restoration: The Status of the Science. Vol. I. Regional Review*. Report EPA/600/3 – 89/038. U.S. Environmental Protection Agency, Environmental Research Laboratory, Carvallis, OR.

Kusler, J.A., and M.E. Kentula. 1989b. *Wetland Creation and Restoration: The Status of the Science. Vol. II: Perspectives*. Report EPA/600/3 – 89/038. U.S. Environmental Protection Agency, Environmental Research Laboratory, Carvallis, OR.

Kusler, J.A., and M.E. Kentula. 1990. "Executive Summary." *in: Wetland Creation and Restoration: The Status of the Science*. Island Press, Washington, D.C. 591 p.

Laine, A., R. Kamula, and J. Hooli. 1998. "Fish and Lamprey Passage in a combined Denil and Vertical Slot Fishway." *Fisheries Management and Ecology* 5(1):31-44.

LaJeone, L.J., and R.G. Monzingo. 2000. "316(b) and Quad Cities Station, Commonwealth Edison Company." *Environmental Science & Policy* 3:S313-S322.

Laney, R.W. 1997. "The Relationship of Submerged Aquatic Vegetation (SAV) Ecological Value to Species Managed by the Atlantic States Marine Fisheries Commission (ASMFC): Summary for the ASMFC SAV Subcommittee." Pages 13-37 *in*: *Atlantic Coastal Submerged Aquatic Vegetation: A Review of its Ecological Role, Anthropogenic Impacts, State Regulation, and Value to Atlantic Coastal Fish Stocks.* C.D. Stephan and T.E. Bigford (eds.). Atlantic States Marine Fisheries Commission Habitat Management Series #1.

Larinier, M., and F. Travade. 1999. "The Development and Evaluation of Downstream Bypasses for Juvenile Salmonids at Small Hydroelectric Plants in France." Pages 25-42 *in*: *Innovations in Fish Passage Technology*. M. Odeh (ed.). American Fisheries Society, Bethesda, MD.

Lathrop, R.G., M.B. Cole, and R.D. Showalter. 2000. "Quantifying the Habitat Structure and Spatial Pattern of New Jersey (U.S.A.) Salt Marshes Under Different Management Regimes." *Wetlands Ecology and Management* 8:163-172.

Leber, K.M., S.M. Arce, D.A. Sterritt, and N.P. Brennan. 1996. "Marine Stock-Enhancement Potential in Nursery Habitats of Striped Mullet *Mugil Cephalus*, in Hawaii." *Fisheries Bulletin* 94(3):452-471.

Levin, L.A., and T.S. Talley. 2002. "Natural and Manipulated Sources of Heterogeneity Controlling Early Faunal Development of a Salt March." *Ecological Applications* 12(6):1785-1802.

Levine, J. 2002. Personal communication from Levine (Levine-Fricke) to L. Urquidi (Argonne National Laboratory, Argonne, IL).

Lindberg, W.J. 1997. “Can Science Resolve the Attraction-Production Issue?” *Fisheries* 22(4):10-13.

Lindig-Cisneros, R., and J.B. Zedler. 2002. “Halophyte Recruitment in a Salt Marsh Restoration Site.” *Estuaries* 25(6A):1174-1183.

Lindig-Cisneros, R., J. Desmond, K.E. Boyer, and J. Zedler. 2003. “Wetland Restoration Thresholds: Can a Degradation Transition be Reversed with Increased Effort?” *Ecological Applications* 13(1):193-205.

Mallen-Cooper, M. 1999. “Developing Fishways for Nonsalmonid Fishes: A Case Study from the Murray River, Australia.” Pages 173-196 *in: Innovations in Fish Passage Technology*, M. Odeh (ed.). American Fisheries Society, Bethesda, MD.

Maloney, T., S. Gephard, and J. Monroe. 2000. *Providing Fish Passage around Dams in the Northeast, a Fishway for Your Stream*. Connecticut River Watershed Council, Inc., Easthampton, MA.

Marble, A.D. 1992. *A Guide to Wetland Funcitonal Design*. Lewis Publishers, Boca Raton, FL.

Marsden, J.E., and M. Chotowski. 2001. “Lake Trout Spawning on Artificial Reefs and the Effect of Zebra Mussels: Fatal Attraction?” *Journal of Great Lakes Research* 27:33-43.

Marsden, J.E., D.L. Perkins, and C.C. Kreuger. 1995. “Recognition of Spawning Areas by Lake Trout: Deposition and Survival of Eggs on Small Man-Made Rock Piles.” *Journal of Great Lakes Research* 21:330-336, Supplement 1.

Maryland Department of Natural Resources. 1999. *Anadromous Fish Restoration in the Susquehanna*. PPRP Power Plant Update, Vol. 5, No. 4, Summer 1999.

McCrain, G. 1992. “Habitat Evaluation Procedures (HEP) Applied to Mitigation Banking in North Carolina.” *Journal of Environmental Management* 35,153-162.

McNair, M. (compiler). 2001. *Alaska Salmon Enhancement Program 2000 Annual Report*. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska. Available at: http://www.cf.adfg.state.ak.us/geninfo/pubs/rir/5J01-01.pdf.

MDNR – see Maryland Department of Natural Resources.

Mehan, G. 2001. Testimony of G. Tracy Mehan III, Assistant Administrator for Water, U.S. Environmental Protection Agency, Before the Subcommittee on Water Resources and the Environment of the Committee on Transportation and Infrastructure, U.S. House of Representatives, Sept. 20.

Michigan Department of Natural Resources. 2002. *Why We Have Hatcheries*. Michigan Department of Natural Resources, Lansing, MI. Available at: http://www.michigan.gov/dnr/1,1607,7-153-10364_10949-32816--,00.html.

Miller, M.J., and K.W. Able. 2002. "Movement and Growth of Tagged Young-of-the-Year Atlantic Croaker (*Micropogonia undulatus L.*) in Restored and Reference Marsh Creeks in Delaware Bay, USA." *Journal of Experimental Marine Biology and Ecology* 267:15-33

Miller, M.J., D.M. Nemerson, and K.W. Able. 2003. "Seasonal Distribution, Abundance, and Growth of Young-of-the-year Atlantic Croaker (*Micropogonias undulatus*) in Delaware Bay and Adjacent Marshes." *Fishery Bulletin* 101(1):100-115.

Minello, T.J., and R.J. Zimmerman. 1992. "Utilization of Natural and Transplanted Texas Salt Marshes by Fish and Decapod Crustaceans." *Marine Ecology Progress Series* 90:273-285.

Mirant Corporation. 2002. *Commitment to the Environment Mirant in the Mid-Atlantic: Raising the Environmental Standard*. Atlanta, GA. Available at: http://www.mirant.com/commitment/environment/midatlantic.html.

Missouri Levee and Drainage District Association. 2000. *Missouri Agricultural Wetland Mitigation Bank Pilot Project, Wetland Restoration Cost Estimate*.

Mitsch, W.J. 2000. "Self Design Applied to Coastal Restoration: An Application of Ecological Engineering." *in: Concepts and Controversies in Tidal marsh Ecology*. M.P. Weinstein and D.A. Kreuger (eds.). Klauwer Academic Publishers, Norwell, MA.

Mitsch, W.J., and J. Gosselink, 1993, *Wetlands*. 2nd Edition. Van Nostrand Reinhold, New York, NY.

Mitsch, W.J., Z. Wu, R.W. Nairn, P.E. Weike, N. Wang, R. Deal, and C.E. Boucher. 1999. "Creating and Restoring Wetlands." *Bioscience* 48(12):1019-1030.

MLDDA – see Missouri Levee and Drainage District Association.

Monaco, M.E. 1995. *Comparative Analysis of Estuarine Bio-Physical Characteristics and Trophic Structure: Defining Ecosystem Function to Fishes*. Ph.D. thesis, The University of Maryland, College Park, MD. 389 p.

Muir Hotaling, N.E., W.J. Kuenzel, and L.W. Douglass. 2002. "Breeding Season Bird Use of Restored Wetlands in Eastern Maryland." *Southeastern Naturalist* 1(3):233-252.

Muth, R.T., L.W. Crist, K.E. LaGory, J.W. Hayse, K.R. Bestgen, T.P. Ryan, J.K. Lyons, and R.A. Valdez. 2000. *Flow and Temperature Recommendations for Endangered Fishes in the Green River Downstream of Flaming Gorge Dam, Final Report*. Upper Colorado River Endangered Fish Recovery Program Project FG-53, U.S. Fish and Wildlife Service, Lakewood, CO.

National Marine Fisheries Service. 2000. *Summary of Research Related to Transportation of Juvenile Anadromous Salmonids around Snake and Columbia River Dams*. White Paper, Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA.

National Marine Fisheries Service. 2001. *Guidelines for Salmonid Passage at Stream Crossings*. Santa Rosa, CA.

National Marine Fisheries Service. 2002. *Draft National Artificial Reef Plan Revision*. Office of Constituent Services, Silver Spring, MD. Available at: http://www.nmfs.noaa.gov/irf/NARP.PDF.

National Oceanic and Atmospheric Administration. 1995. *Habitat Equivalency Analysis: An Overview*. Damage Assessment and Restoration Program, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, MD.

National Oceanic and Atmospheric Administration. 1997. *Natural Resource Damage Assessment Guidance Document: Scaling Compensatory Restoration Actions (Oil Pollution Act of 1990)*. NOAA Damage Assessment and Restoration Program, Silver Spring, MD.

National Oceanic and Atmospheric Administration. 2000. *Habitat Equivalency Analysis: An Overview*. Damage Assessment and Restoration Program, NOAA Restoration Center, Silver Spring, MD.

National Research Council. 1995. *Wetlands: Characteristics and Boundaries*. Committee on Characterization of Wetlands, National Academy Press, Washington, D.C. 308 p.

National Research Council. 2001. *Compensating for Wetland Losses Under the Clean Water Act*. Committee on Mitigating Wetland Losses, National Academy Press, Washington, D.C.

Native Fish Conservancy. 2002. *Migratory Fish Restoration and Passage on the Susquehanna River. Native Fish Conservancy*. Available at: http://www.nativefish.org/Articles/Migratory-Fish-Restoration.htm.

Natural Resources Conservation Service. 1998a. *Conservation Practice Standard: Wetland Restoration, Code 657*. U.S. Department of Agriculture, Washington, D.C., Aug.

Natural Resources Conservation Service. 1998b. *Conservation Practice Standard: Wetland Creation, Code 658*. U.S. Department of Agriculture, Washington, D.C. Aug.

Natural Resource Conservation Service. 2000. *Vegetation Restoration Recommendations: Bottom-Land Hardwood* Forests. Wetland Restoration Information Series Number 1.

Nature Conservancy — see The Nature Conservancy.

Neander, J. 2002. Personal communication from Neander (California Environmental Resources Evaluation System) to L. Urquidi (Argonne National Laboratory, Argonne, IL).

New Jersey Department of Environmental Protection. 2000. "Fact Sheet for a Draft NJPDES Permit Including Section 316(a) Variance Determination and Section 316(b) Decision, Permit No. NJ0005622." Division of Water Quality.

New Jersey Department of Environmental Protection. 2002. *Frequently Asked Questions Regarding the Salem NJPDES Permit*. New Jersey Department of Environmental Protection, Trenton, NJ. Available at: http://www.state.nj.us/dep/dwq/pdf/salemfaq.pdf.

New Jersey Department of Environmental Protection. Undated. *Fact Sheet for a Draft NJPDES Permit Including Section 316(a) Variance Determination and Section 316(b) Decision*. Permit No. NJ0005622, New Jersey Department of Environmental Protection, Trenton, NJ. Available at: http://www.state.nj.us/dep/dwq/pdf/factsht.pdf.

New York State Department of Environmental Conservation. 2002. *A Look at DEC Fish Hatcheries*. Albany, NY. Available at: http://www.dec.state.ny.us/website/dfwmr/fish/99fish.htm.

Nixon, S.W., and C. Oviatt. 1973. "Ecology of a New England Salt Marsh." *Ecological Monographs* 43:463-498.

NJDEP – see New Jersey Department of Environmental Protection.

NMFS – see National Marine Fisheries Service.

NOAA – see National Oceanic and Atmospheric Administration.

Northwest Fisheries Science Center. Undated a. *Broodstock Technology Needed to Restore Depleted Pacific Salmon Stocks*. NWFSC Issue Paper REUT 6202 (HQ ID 290). Resource Enhancement and Utilization Technologies Division, Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, WA.

Northwest Fisheries Science Center. Undated b. *Developing Methods to Identify and Control Pathogenic Microorganisms that Threaten Fishery Resources*. NWFSC Issue Paper REUT 6205 (HQ ID 299). Resource Enhancement and Utilization Technologies Division, Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, WA.

NRCS – see Natural Resources Conservation Service.

NWFSC – see Northwest Fisheries Science Center.

Oak Ridge National Laboratory. 1999. *EPRI's CompMech Suite of Modeling Tools for Population-Level Impact Assessment*. Available at: http://www.esd.ornl.gov/programs/COMPMECH/brief.html. Accessed Oct. 10, 2002.

Odeh, M. 1999. "Fish Passage Innovation for Ecosystem and Fishery Restoration." Pages 1-24 *in*: *Innovations in Fish Passage Technology*. M. Odeh (ed.). American Fisheries Society, Bethesda, MD.

Odeh, M., J. Noreika, and A. Haro. 1995. *Hydraulic Model Study of Little Falls Dam Passage*. Final Report submitted to U. S. Fish and Wildlife Service, Annapolis, MD, and U. S. Army Corps of Engineers, Baltimore District, Baltimore, MD. 79 pp.

Office of Technology Assessment. 1995. *Fish Passage Technologies*. Congress of the United States, Washington, D.C.

Ohio Legislative Service Commission. 2001. *Fiscal Note and Local Impact Statement*. 124th General Assembly of Ohio, Columbus, OH.

Oldani, N.O., and C.R.M. Baigun. 2002. "Performance of a Fishway System in a Major South American Dam on the Parana River (Argentina-Paraguay)." *River Res. Applic.* 18:171-183.

Olla, B.L., M.W. Davis, and C. H. Ryer. 1998. "Understanding How the Hatchery Environment Represses or Promotes the Development of Behavioral Survival Skills." *Bulletin of Marine Sciences* 62(2):531-550.

OLSC – see Ohio Legislative Services Commission.

ORNL – see Oak Ridge National Laboratory.

Orth, R.J. 2002a. "VIMS field observations #2." E-mail communication from Orth to LRSC@LISTSERV.CHESAPEAKEBAY.NET, May 2.

Orth, R.J. 2002b. "VIMS SAV field observations." E-mail communication from Orth to LRSC@LISTSERV.CHESAPEAKEBAY.NET, April 23.

OTA – see Office of Technology Assessment.

Pastorok, R., and A. MacDonald. 1996. "Chapter 2. Ecological Planning Process for Restoration Projects." In: Yozzo, D., J. Titre, and J. Sexton (eds.), *Planning and Evaluating Restoration of Aquatic Habitats from an Ecological Perspective*. IWR Report 96-EL-4, U.S. Army Corps of Engineers, Institute for Water Resources, Alexandria, VA.

Patterson, P. 2001. Cover letter with enclosure: NJPDES permit renewal for PSEG Nuclear LLC, Salem Generating Station. Division of Water Quality, New Jersey Department of Environmental Protection. June 29.

Peacock, B. 2001. *Habitat Equivalency Analysis: Conceptual Background and Hypothetical Example*. National Park Service, Environmental Quality Division, Washington, DC.

Peake, S., R.S. McKinley, and D.A. Scruton. 1997. "Swimming Performance of Various Freshwater Newfoundland Salmonids Relative to Habitat Selection and Fishway Design." *Journal of Fisheries Biology* 51: 710-723.

Pearsons, T.N., and C.W. Hopley. 1999. "A Practical Approach for Assessing Ecological Risks Associated with Fish Stocking Programs." *Fisheries* 24(9):16-23.

Penn, T., and T. Tomasi. 2002. "Calculating Resource Restoration for an Oil Discharge in Lake Barre, Louisiana, USA." *Environmental Management* 29(5):691–702.

Pennsylvania Fish and Boat Commission. Undated. *Migratory Fish Restoration and Passage on the Susquehanna River*. Available at: http://sites.state.pa.us/PA_Exec/Fish_Boat/migfishs.pdf

Pennsylvania Fish and Boat Commission. 2001. *2001 A Shad Odessey*. Fact sheet. Available at: http://sites.state.pa.us/PA_Exec/Fish_Boat/shad01.htm.

Perry, J.E., T.A. Barnard, Jr., J.G. Bradshaw, C.T. Friedrichs, K.J. Havens, P.A. Mason, W.I. Priest, III, and G.M. Silberhorn. 2001. "Creating Tidal Salt Marshes in the Chesapeake Bay." *Journal of Coastal Research* 27:170-191.

Peven, C.M., and T.R. Mosey. 1999. "Development of Surface Bypass and Collection at Rocky Reach Dam, Columbia River." Pages 79-92 *in*: *Innovations in Fish Passage Technology*. M. Odeh (ed.). American Fisheries Society, Bethesda, MD.

PFBC – see Pennsylvania Fish and Boat Commission.

Philippart, J.C. 1995. "Is Captive Breeding an Effective Solution for the Preservation of Endemic Species?" *Biological Conservation* 72(2):281-295.

Ploskey, G.R., and T.J. Carlson. 1999. "Comparison of Hydroacoustic and Net Estimates of Fish Guidance Efficiency of an Extended Submersible Bar Screen at John Day Dam." *North American Journal of Fisheries Management* 19(4):1066-1079.

Polovina, J.J. 1991. "Evaluation of Hatchery Releases of Juveniles to Enhance Rockfish Stocks, with Application to Pacific-Ocean Perch *Sebastes alutus*." *Fishery Bulletin* 89(1):129-136.

Poulakis, G.R., J.M. Shenker, and D.S. Taylor. 2002. "Habitat Use by Fishes after Reconnection of an Impounded Estuarine Wetland in the Indian River Lagoon, Florida (USA)." *Wetlands Ecology and Management* 10:51-69.

Press, D., D.F. Doak, and P. Steinberg. 1996. "The Role of Local Government in the Conservation of Rare Species." *Conservation Biology* 10(6):1538-1548.

PSEG – see Public Service Enterprise Group.

PSE&G – see Public Service Electric & Gas.

Public Service Electric & Gas. 1996a. "Estuary Enhancement Program, Fact Sheet No.3: Wetland Restoration." Trenton, NJ.

Public Service Electric & Gas. 1996b. "Estuary Enhancement Program, Fact Sheet No. 6: Management Plans." Trenton, NJ.

Public Service Electric & Gas. 1996c. "Estuary Enhancement Program, Fact Sheet No. 8: Public Participation." Trenton, NJ.

Public Service Electric & Gas. 1999. *Estuary Update, Spring 1999*. Available at: http://www.pseg.com/companies/nuclear/estuary/newsletters/spring2000.pdf.

Public Service Enterprise Group. 1999a. *Renewal Application for the Salem Generating Station, New Jersey Pollutant Discharge Elimination System Permit Renewal Application, Attachment G-2. Wetland Restoration Success*. Newark, NJ.

Public Service Enterprise Group. 1999b. *Renewal Application for the Salem Generating Station, New Jersey Pollutant Discharge Elimination System Permit Renewal Application, Attachment G-4. Bioenergetic Modeling of Restored and Reference Wetland Sites*. Newark, NJ.

Public Service Enterprise Group. 2003. *Fish Ladders Overview*. Available at: http://www.pseg.com/companies/nuclear/estuary/fish_ladders/overview.html.

Race, M.S., and M.S. Fonseca. 1996. "Fixing Compensatory Mitigation: What It Will Take." *Ecological Applications* 6(1):94-101.

RAE-ERF – see Restore America's Estuaries-Estuarine Research Federation.

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

Raposa, K. 2002. "Early Responses of Fishes and Crustaceans to Restoration of a Tidally Restricted New England Salt Marsh." *Restoration Ecology* 10(4):665-676.

Raposa, K.B., and C.T. Roman. 2003. "Using Gradients in Tidal Restriction to Evaluate Nekton Community Responses to Salt Marsh Restoration." *Estuaries* 26(1):98-105.

Restore America's Estuaries-Estuarine Research Federation. 1999. *Principles of Estuarine Habitat Restoration, Working Together to Restore America's Estuaries, Report on the RAE-ERF Partnership, Year One, September 1999*. Available at: www.estuaries.org.

Richards, R.A., and P.J. Rago. 1999. "A Case History of Effective Fishery Management: Chesapeake Bay Striped Bass." *North American Journal of Fisheries Management* 19(2):356-375.

Rivinoja, P., S. McKinnell, and H. Lindqvist. 2001. "Hindrances to Upstream Migration of Atlantic Salmon (*Salmo salar*) in a Northern Swedish River Caused by a Hydroelectric Power-Station." *Regul. Rivers: Res. Mgmt*. 17: 101-115.

Robb, J.T. 2001. *Indiana Wetland Compensatory Mitigation: Area Analysis*. Prepared by the Indiana Department of Environmental Management, Indianapolis, IN, for U.S. Environmental Protection Agency, Region 5 Acquisition and Assistance Branch, Chicago, IL. 32pp.

Roman, C.T., K.B. Raposa. S. C. Adamowicz, M.J. James-Pirri, and J.G. Catena. 2002. "Quantifying Vegetation and Nekton Response to Tidal Restoration of a New England Salt Marsh." *Restoration Ecology* 10(3):450-460.

Rountree, R.A., and K.W. Able. 1992. "Fauna of Polyhaline Subtidal Marsh Creeks in Southern New Jersey: Composition, Abundance and Biomass." *Estuaries* 15(2):171-185.

Rountree, R.A., and K.W. Able. 1993. "Diel Variation in Decapod Crustacean and Fish Assemblages in New Jersey Polyhaline Marsh Creeks." *Est. Coast. Shelf Sci*. 37:181-201.

Rozas, L.P., and T.J. Minello. 2001. "Marsh Terracing as a Wetland Restoration Tool for Creating Fishery Habitat." *Wetlands* 21(3): 327-341.

Rozas, L.P., and W.E. Odum. 1988. "Occupation of Submerged Aquatic Vegetation by Fishes: Testing the Roles of Food and Refuge." *Oecologia* 77:101-106.

Rozas, L.P., C.C. McIvor, and W.E. Odum, 1988. "Intertidal Rivulets and Creekbanks: Corridors between Tidal Creeks and Marshes." *Marine Ecology Progress Series* 47:303-307.

Rulifson, R.A., and R.W. Laney. 1999. *Striped Bass Stocking Programs in the United States: Ecological and Resource Management Issues*. Canadian Stock Assessment Secretariat Research Document 99/007. Fisheries and Oceans Canada, Ottawa, Canada.

Sacco, J. 2002. Personal communication from Sacco (Harbor Spill Committee) to L. Urquidi (Argonne National Laboratory, Argonne, IL).

Sale, M.J., G.F. Cada, L.H. Chang, S.W. Christensen, S.F. Railsback, J.E. Francfort, B.N. Rinehart, and G.L. Sommers. 1991. *Environmental Mitigation at Hydroelectric Projects; Volume 1: Current Practices for Instream Flow Needs, Dissolved Oxygen, and Fish Passage*. Prepared by Oak Ridge National Laboratory, Oak Ridge, TN, and Idaho National Engineering Laboratory, Idaho Falls, ID, for the U.S. Department of Energy, Assistant Secretary for Conservation and Renewable Energy, Washington, D.C.

Savino, J.F., E.A. Marschall, and R.A. Stein. 1992. "Bluegill Growth as Modified by Plant Stem Density: An Exploration of Underlying Mechanisms." *Oecologia* 89:153-160.

Sawhill, J.C.  1996.  "Creating Biodiversity Partnerships: The Nature Conservancy Perspective." *Environmental Management* 20(6):789-792.

Schoenbaum, T.J., and R. B. Stewart. 2002. "The Role of Mitigation and Conservation Measures in Achieving Compliance with Environmental Regulatory Statutes: Lessons Learned from Section 316 of the Clean Water Act." *N.Y. U. Environmental Law Journal* 8:237-331.

Scientific and Technical Advisory Committee. 2002. *The Optimization of Benefits from Wetlands Restoration, A Workshop*. STAC Publication 01-001. Available at: http://www.chesapeake.org/stac/pubs/wrkshops/WetlandsReportWeb.pdf.

Seaman, W.J., Jr. 1997. "What if Everyone Thought About Artificial Reefs?" *Fisheries* 22(4):4-5.

Seaman, W., Jr., and L.M. Sprague (eds.). 1991. *Artificial Habitats for Marine and Freshwater Fisheries*. Academic Press, San Diego, CA. 285 pp.

Secor, D.H., and E.D. Houde. 1998. "Use of Larval Stocking in Restoration of Chesapeake Bay Striped Bass." *ICES Journal of Marine Sciences* 55(2):228-239.

Sheehan, R.J., and J.L. Rasmussen. 1993. "Large Rivers." Chapter 19, pp. 445-468 *in: Inland Fisheries Managment in North America*. C.C. Kohler and W.A. Hubert (eds.). American Fisheries Society, Bethesda, MD. pp. 445-468.

Sherman, R.L., D.S. Gilliam, and R.E. Spieler. 2002. "Artificial Reef Design: Void Space, Complexity, and Attractants." *ICES Journal Marine Science* 59:S196-S200.

Shisler, J.K. 1989. "Creation and Restoration of Coastal Wetlands of the Northeastern United States." Pages 145-165 *in: Wetlands Creation and Restoration. The Status of the Science*. Report EPA 600/3-89/038A, Vol. 1. J.A. Kusler and M.E. Kentula (eds.). U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR.

Simenstad, C.A., and R. M Thom. 1996. "Functional Equivalency Trajectories of the Restored Gog-Le-Hi-Te Estuarine Wetland." *Ecological Applications* 6(1):38-56.

Simenstad, C.A., W.G. Hood, R.M. Thom, D.A. Levy, and D.L. Bottom. 2000. "Landscape Structure and Scale Constraints on Restoring Estuarine Wetlands for Pacific Coast Juvenile Fishes. *In: Concepts and Controversies in Tidal Marsh Ecology*. M.P. Weinstein and D.A. Kreeger (eds.). Kluwer Academic Publishers, Norwell, MA.

Slatick, E. 1975. "Laboratory Evaluation of a Denil-Type Steeppass Fishway with Various Entrance and Exit Conditions for Passage of Adult Salmonids and American Shad." *Marine Fisheries Review* 37(9):17-26.

Slatick, E., and L.R. Basham. 1985. "The Effect of Denil Fishway Length on Passage of Some Nonsalmonid Fishes." *Marine Fisheries Review* 47(1):83-85.

Smith, R.K., and R.A. Bleistine. 2002. "The Lower Susquehanna River: Shad, Eagles, and Wildflowers." *Hydro Review* May 2002:SR12-SR15.

Society of Wetlands Scientists. 2001. "Position Paper on Performance Standards for Wetland Restoration and Creation." *Society of Wetland Scientists Bulletin* 18(4):21-23.

South Atlantic Fishery Management Council. 1997. "SAFMC Policy for Protection and Enhancement of Marine Submerged Aquatic Vegetation (SAV) Habitat." Appendix 2 *in*: *Atlantic Coastal Submerged Aquatic Vegetation: A Review of its Ecological Role, Anthropogenic Impacts, State Regulation, and Value to Atlantic Coastal Fish Stocks*. C.D. Stephan and T.E. Bigford (eds.). Atlantic States Marine Fisheries Commission Habitat Management Series #1.

Southern California Edison. 2000. *Marine Fish Hatchery*. Available at: http://www.sce.com/sc3/006_about_sce/006b_generation/006b1_songs/006b1c_env_prot/006b1c3_so.

Southern Division AFS Reservoir Committee. 2000. *Habitat Manual for Use of Artificial Structures in Lakes and Reservoirs*. Available at: http://www.sdafs.org/reservor/manuals/habitat/main.htm

STAC – see Scientific and Technical Advisory Committee.

Stafford, C.P., and T.A. Haines. 1997. "Mercury Concentrations in Maine Sport Fishes." *Transactions of the American Fisheries Society* 126(1):144-152.

Steig, T.W., and R. Adeniyi. 1999. "Hydroacoustic Evaluation of Fish Passage through a Prototype Surface Bypass Collector at Rocky Reach Dam." Pages 93-104 *in*: *Innovations in Fish Passage Technology*. M. Odeh (ed.). American Fisheries Society, Bethesda, MD.

Steimle, F.W., and M.H. Meier. 1997. "What Information Do Artificial Reef Managers Really Want from Fishery Science?" *Fisheries* 22(4):6-8.

Stephens, J., Jr., and D. Pondella II. 2002. "Larval Productivity of a Mature Artificial Reef: The Ichthyoplankton of King Harbor, California, 1974-1997." *ICES Journal Marine Science* 59:S51-S58.

Stephens, J.S., Jr., P.A. Morris, D.J. Pondella, T.A. Koonce, and G.A. Jordan. 1994. "Overview of the Dynamics of an Urban Artificial Reef Fish Assemblage at King Harbor, California, USA, 1974-1991: A Recruitment-Driven System." *Bulletin of Marine Science* 55(2-3):1224-1239.

Stickney, R.R. 1994. "Use of Hatchery Fish in Enhancement Programs." *Fisheries* 19(5):6-13.

Strange, E., H. Galbraith, S. Bickel, D. Mills, D. Melton, and J. Lipton. 2002. "Determining Ecological Equivalence in Service-to-Service Scaling of Salt March Restoration." *Environmental Management* 29(2):290-300.

Sullivan, G. 2001. "Establishing Vegetation in Restored and Created Coastal Wetlands." Chapter 4 *in: Handbook for Restoring Tidal Wetlands*. J. Zedler (ed.). CRC Press, Boca Rotan, FL.

Swamy, V., P.E. Fell, M. Body, M. Keaney, M. Nyaku, E. McIlvain, and A. Keen. 2002. "Macroinvertebrate and Fish Populations in a Restored Impounded Salt Marsh 21 Years after the Reestablishment of Tidal Flooding." *Environmental Management* 29(4):516-530.

SWS: see Society of Wetland Scientists.

Szabo, R., and H. Bleichfeld. 1998. *ISTEA Amendment May Spur Wetlands Mitigation Banking*. Van Ness Feldman, P.C., Natural Resource Articles. Available at: http://www.vnf.com/content/Articles/Articles/artrgs1.htm.

Tampa Bay Estuary Program. 2000. *A Summary of Seagrass Coverage Data for Tampa Bay*. Prepared by Janicki Environmental, Inc. for the Tampa Bay Estuary Program, Saint Petersburg, FL. May. Available at: http://www.tbeptech.org/html/SG2000.htm.

Teal, J.M. 1962. "Energy Flow in the Salt Marsh Ecosystem of Georgia." *Ecology* 43:614-624.

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

Teo, S.L.H., and K.W. Able. 2003. "Growth and Production of the Mummichog (*Fundulus heteroclitus*) in a Restored Salt Marsh." *Estuaries* 26(1):51-63.

Texas Parks and Wildlife. 2002. *Artificial Reefs–Rigs to Reefs*. Available at: http://www.tpwd.state.tx.us/fish/reef/artreef.htm.

Thayer, G.W., H.H. Stuart, W.J. Kenworthy, J.F. Ustach, and A.B. Hall. 1978. "Habitat Values of Salt Marshes, Mangroves, and Seagrasses for Aquatic Organisms." Pages 235-247 *in: Wetland Functions and Values: The State of Our Understanding. Proceedings of the National Symposium on Wetlands*. P.E. Greeson, J.R. Clark and J.E. Clark (eds.). American Water Research Association.

Thayer, G.W., M.S. Fonseca, and J.W. Kenworthy. 1997. Ecological Value of Seagrasses: A Brief Summary for the ASMFC Habitat Committee's SAV Subcommittee." Pages 7-12 *in*: *Atlantic Coastal Submerged Aquatic Vegetation: A Review of Its Ecological Role, Anthropogenic Impacts, State Regulation, and Value to Atlantic Coastal Fish Stocks*. C.D. Stephan and T.E. Bigford (eds.). Atlantic States Marine Fisheries Commission Habitat Management Series #1.

The Nature Conservancy. 2000. *Press Release.* Dec. 21. Available at: http://nature.org/wherewework/northamerica/states/tennessee/press/press168.html.

The Nature Conservancy. 2001. The Nature Conservancy Wins New Funding for Acquisition and Management of Zumwalt Prairie Preserve." *Press Release*. Oct. 18. Available at: http://nature.org/wherewework/northamerica/states/oregon/press/press433.html

The Nature Conservancy. 2002. "The Nature Conservancy Partners with New York State to Protect 44,650 Acres. $9.1 Million for Largest-Ever Conservancy Land Acquisition in New York." *Press Release*. June 10. Available at: http://nature.org/pressroom/press/press673.html

Thom, R. 1996. "Goal Setting and Adaptive Management." Pages 4-1-4-20 *in: Planning and Evaluating Restoration of Aquatic Habitats from an Ecological Perspective*. D. Yozzo, J. Titre and J. Sexton (eds.). Army Corps of Engineers, Vicksburg, MS.

Tobler, W.R. 1970. "A Computer Movie Simulating Urban Growth in the Detroit Region." *Economic Geographer* 46:234-240.

Travis, J., F.C. Coleman, C.B. Grimes, D. Conover, T.M. Bert, and M. Tringali. 1998. "Critically Assessing Stock Enhancement: An Introduction to the Mote Symposium." *Bulletin Marine Science* 62(2): 305-311.

Tucker, B. 1999. *Stocking Fish as a Management Tool?* Alabama Department of Conservation and Natural Resources, Spanish Fort, AL. Available at: http://www.dcnr.state.al.us/agfd/FNAStocking.html.

Tugend, K., M.S. Allen, and M. Webb. 2002. "Use of Artificial Habitat Structures in U.S. Lakes and Reservoirs: A Survey from the Southern Division AFS Reservoir Committee." *Fisheries* 27(5): 22-27.

Tupper, M., and K.W. Able. 2000. "Movements and Food Habits of Striped Bass (*Morone saxatilis*) in Delaware Bay (USA) Salt Marshes: Comparison of a Restored and a Reference Marsh." *Marine Biology* 137(5/6):1049-1058.

USACE – see U.S. Army Corps of Engineers.

USDA – see U.S. Department of Agriculture.

USDOI – see U.S. Department of the Interior.

USEPA – see U.S. Environmental Protection Agency.

USFWS – see U.S. Fish and Wildlife Service.

USGS – see U.S. Geologic Survey.

U.S. Army Corps of Engineers. 1996. "Interagency Compensatory Wetland Mitigation Agreement." Hackensack Meadowlands District, NJ. Dec.

U.S. Army Corps of Engineers. 1998. *Informational Notice: Mitigation Guidelines and Requirements*. Chicago District, Chicago, IL. April 30.

U.S. Army Corps of Engineers. 2001. *Guidance for the Establishment and Maintenance of Compensatory Mitigation Projects under the Corps Regulatory Program Pursuant to Section 404(a) of the Clean Water Act and Section 10 of the River and Harbors Act of 1899*. Regulatory Guidance Letter, Oct. 31.

U.S. Army Corps of Engineers. 2002a. *Columbia River Basin–Dams and Salmon: Adult Fishways at the Dams*. Fact sheet available at: https://www.nwd.usace.army.mil/ps/ fishway.htm.

U.S. Army Corps of Engineers. 2002b. "Fish Management Division USACE Northwestern Division Homepage." Available at: https://www.nwd.usace.army.mil/ps/welcome.htm.

U.S. Army Corps of Engineers. 2002c. *Columbia River Basin–Dams and Salmon: Juvenile Fish Passage at the Dams*. Fact sheet available at: https://www.nwd.usace.army.mil/ps/juvefish.htm.

U.S. Army Corps of Engineers. 2002d. *Columbia River Basin–Dams and Salmon: Juvenile Fish Transportation Program*. Fact sheet available at: https://www.nwd.usace.army.mil/ps/ juvetran.htm.

U.S. Army Corps of Engineers. 2002e. *Pacific Salmon Coordination Office, Columbia River Basin - Dams and Salmon Research: Anadromous Fish Evaluation Program*. USACE Northwestern Division. Available at: http://www.nwd.usace.army.mil/ps/research.htm.

U.S. Army Corps of Engineers. 2002f. *The Dalles/John Day/Willow Creek Project.* Portland District, WA. Available at: https://www.nwp.usace.army.mil/op/D/ standard/jd/fish/jd_fish.htm.

U.S. Department of Agriculture. 1980. *Habitat Evaluation Procedures*. Fish and Wildlife Service, Division of Ecological Services, Washington, D.C.

U.S. Department of the Interior. 2002. *Endangered Fish Passage Project at the Grand Valley Project Diversion Dam and Fish Screen in the Government Highline Canal, Draft Environmental Assessment*. Bureau of Reclamation, Upper Colorado Region, Western Colorado Area Office, Grand Junction, CO.

U.S. Environmental Protection Agency. 1996. *Draft Framework for Watershed-Based Trading*. EPA 800-R-96-001, Washington, DC.

U.S. Environmental Protection Agency. 1997. *Guidance for Evaluating the Adverse Impact of Cooling Water Intake Structures on the Aquatic Environment: Section 316(b).* P.L. 92-500 at 15 (draft May 1, 1977, 1977 Guidance), Permit Division, Office of Water Enforcement, Washington, D.C.

U.S. Environmental Protection Agency. 1998. *Guidelines for Ecological Risk Assessment*, EPA/630/R-95/002F. Risk Assessment Forum, Washington, DC.

U.S. Environmental Protection Agency. 2001a. *Draft Initial Cost Estimates Prepared for the May 23, 2001 Public Meeting of Technical Experts to Review EPA's Preliminary Data on Cooling Water Intake Structure Technologies in Place at Existing Facilities and Their Costs*. Office of Science and Technology, Washington, D.C.

U.S. Environmental Protection Agency. 2001b. *National Estuary Program Profiles: List of Programs*. Available at: http://www.epa.gov/owow/estuaries/list.htm. (Updated June 22, 2001).

U.S. Environmental Protection Agency. 2002a. *Economic and Benefits Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule*. Report EPA-821-R-02-001. Office of Water, Washington D.C.

U.S. Environmental Protection Agency. 2002b. *Return of the Natives: Restoring Fish Runs on the Blackstone River*. Washington, D.C.

U.S. Environmental Protection Agency. 2002c. "40 CFR Parts 9, et al., National Pollutant Discharge Elimination System - Proposed Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities: Proposed Rule." *Federal Register* Vol. 67, No. 68, pp. 17122–17170, April 9.

U.S. Environmental Protection Agency. 2003. "National Pollutant Discharge Elimination System – Proposed Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities; Notice of Data Availability; Proposed Rule." *Federal Register*, Part IV, 40 CFR Part 125, March 19.

U.S. Environmental Protection Agency et al. 1995. "Federal Guidance for the Establishment, Use and Operation of Mitigation Banks." *Federal Register*, Vol. 60, p. 58605, Nov. 28.

U.S. Fish and Wildlife Service. 2002a. *Recovery of Upper Colorado River Basin Fish*. Upper Colorado River Endangered Fish Recovery Program, Lakewood, CO. Available at: http://www.r6.fws.gov/coloradoriver/Crrphtc1.htm.

U.S. Fish and Wildlife Service. 2002b. *National Fish Hatchery System*. Washington, D.C. Available at: http://fisheries.fws.gov/FWSFH/NFHSintro.htm.

U.S. Fish and Wildlife Service. 2002c. *FWS FY 2003 Budget Proposal*. Division of Budget, Washington, D.C. Available at: http://budget.fws.gov/FY%202003%20GB/06.02%hatchery%20ops&main.pdf.

U.S. Fish and Wildlife Service. 2002d. *National Fish Hatcheries*. Division of the National Fish Hatcheries, Washington, D.C. Available at: http://fisheries.fws.gov/FWSFH/NFH.html.

U.S. Fish and Wildlife Service. 2002e. *National Fish Passage Program*. Available at: http://fisheries.fws.gov/FWSMA/FishPassage/index.htm.

U.S. Fish and Wildlife Service. 2002f. *Tahuya River (WRIA 15-0470), WA*. Region 1, Portland, OR. Available at: http://fisheries.fws.gov/FWSMA/FishPassage/region1.htm.

U.S. Fish and Wildlife Service. 2002g. *Honobia Creek at Bridge Six, OK*. Region 2, Albuquerque, NM. Available at: http://fisheries.fws.gov/FWSMA/FishPassage/region2.htm.

U.S. Fish and Wildlife Service. 2002h. *East Machias River, ME*. Region 5, Albuquerque, NM. Available at: http://fisheries.fws.gov/FWSMA/FishPassage/region5.htm.

U.S. Fish and Wildlife Service. 2002i. *Rains Mills Dam Removal, Little River–Neuse Basin, NC*. Region 4, Atlanta, GA. Available at: http://fisheries.fws.gov/FWSMA/FishPassage/region4.htm.

U.S. Fish and Wildlife Service. 2002j. *Merritt Island Dike Removal, FL*. Region 4, Atlanta, GA. Available at: http://fisheries.fws.gov/FWSMA/FishPassage/region4.htm.

U.S. Fish and Wildlife Service. 2002k. *Improving the River Habitat*. Upper Colorado River Endangered Fish Recovery Program, Lakewood, CO. Available at: http://www.r6.fws.gov/coloradoriver/Index.htm.

U.S. Fish and Wildlife Service. 2003. *National Coastal Wetlands Conservation Grant Program: Helping States Conserve Their Coastal Wetlands*. Division of Fish and Wildlife Management and Habitat Restoration, Arlington, Virginia. Available at: http://www.fws.gov/cep/cwgcover.html.

Veil, J.A. 1997. *The Feasibility of Effluent Trading in the Energy Industries*. Prepared by Argonne National Laboratory for U.S. Department of Energy, Washington, D.C. May.

Veil, J. 1998. “The Potential for Effluent Trading in the Energy Industries.” *Environmental Science and Policy* 1:39-49.

VIMS – see Virginia Institute of Marine Science.

Virginia Institute of Marine Science. 2002. *Bay Grasses (SAV) in Chesapeake Bay*. VIMS SAV Mapping Lab. Available at: http://www.vims.edu/bio/sav/.

Virginia Marine Resources Commission. 1998. *Guidelines for the Establishment, Use, and Operation of Tidal Wetland Mitigation Banks in Virginia.* Developed jointly by the Virginia Marine Resources Commission and Virginia Institute of Marine Science under Virginia Coastal Resources Management Program Grant CZM97-429-1.

Vivian-Smith, G. 2001. “Developing a Framework for Restoration.” Chapter 2 *in: Handbook for Restoring Tidal Wetlands*. J. Zedler (ed.). CRC Press, Boca Rotan, FL.

VMRC – see Virginia Marine Resources Commission.

Wainright, S.C., M.P. Weinstein, K.W. Able, and C.A. Currin. 2000. “Relative Importance of Benthic Macroalgae, Phytoplankton and the Detritus of Smooth Cordgrass (*Spartina*) and the Common Reed (*Phragmites*) to Brackish Marsh Food Webs.” *Marine Ecology Progress Series* 200:77-91.

Walters, C.J., and C.S. Holling. 1990. “Large-Scale Management Experiments and Learning by Doing.” *Ecology* 71:2060-2068.

Waples, R.S. 1999. “Dispelling Some Myths about Hatcheries.” *Fisheries* 24(2):12-21.

Washington Department of Fish and Wildlife. 1997. *WDFW Hatcheries Program Statistics*. Available at: http://www.wa.gov/wdfw/hat/hat-stat.htm.

Wattendorf, B. 2002. *Freshwater Fisheries Updates: Florida’s Fish Hatcheries*. Florida Fish and Wildlife Conservation Commission, Division of Freshwater Fisheries, Tallahassee, FL. Available at: http://floridafisheries.com/updates/hatchlbr.html.

Weinstein, M.P. 1979. “Shallow Marsh Habitats as Primary Nurseries for Fishes and Shellfish, Cape Fear River, North Carolina.” *Fisheries Bulletin* 77:339-357.

Weinstein, M.P. 1998. “What Begets Success?” *in: Wetlands Engineering and River Restoration*. Proc. Amer. Soc. Civil Engin. Conf. D.F. Hayes (ed.). March 22-28, Denver, CO.

Weinstein, M.P., and D.A. Kreeger. 2000. *Concepts and Controversies in Tidal Marsh Ecology*. Kluwer Academic Publishers, Norwell, MA.

Weinstein, M.P., J.H. Balletto, J.M. Teal, and D.F. Ludwig. 1997. “Success Criteria and Adaptive Management for a Large-Scale Wetland Restoration Project.” *Wetlands Ecology and Management* 4(2):111-127.

Weinstein, M.P., K.R. Phillipp, and P. Goodwin. 2000a. “Catastrophes, Near-Catastrophes and the Bounds of Expectation: Success Criteria for Macroscale Marsh Restoration. *In: Concepts and Controversies in Tidal Marsh Ecology*. M.P. Weinstein and D.A. Kreeger (eds.). Kluwer Academic Publishers, Norwell, MA. 875 p.

Weinstein, M.P., S.Y. Litvin, K.I. Bosley, C.M. Fuller, and S.C Wainright. 2000b. “The Role of Tidal Salt Marsh as an Energy Source for Juvenile Marine Transient Finfishes: A Stable Isotope Approach.” *Transactions of the American Fisheries Society* 129:797-810.

Weinstein, M.P., J.M. Teal, J.H. Balletto, and K.A. Strait. 2001. “Restoration Principles Emerging from one of the World's Largest Tidal Marsh Restoration Projects.” *Wetlands Ecology and Management* 9:387-407.

White, P.S., and J.L. Walker. 1997. “Approximating Nature’s Variation: Selecting and Using Reference Information in Restoration Ecology.” *Restoration Ecology* 5:338-349.

Whitney, R.R., L.D. Calvin, M.W. Erho, Jr., and C.C. Coutant. 1997. *Downstream Passage for Salmon at Hydroelectric Projects in the Columbia River Basin: Development, Installation, and Evaluation*. Prepared for the Northwest Power Planning Council, Portland, OR.

Wieringa, M., and A. Morton. 1996. “Hydropower, Adaptive Management, and Biodiversity.” *Environmental Management* 20:831-840.

Wilding, T.A., and M.D.J. Sayer. 2002. “Evaluating Artificial Reef Performance: Approaches to Pre- and Post-Deployment Research.” *ICES Journal Marine Science* 59:S222-S230.

Wilhere, G.F. 2002. “Adaptive Management in Habitat Conservation Plans.” *Conservation Biology* 16(1):20-29.

Wilkey, P., R. Sundell, K. Bailey, and D. Hayes. 1994. *Wetland Mitigation Banking for the Oil and Gas Industry: Assessment, Conclusions, and Recommendations*. Report ANL/ESD/TM-63. Argonne National laboratory, Argonne, IL.

Will, T.A., T.R. Reinert, and C.A. Jennings. 2002. "Maturation and Fecundity of a Stock-Enhanced Population of Striped Bass in the Savannah River Estuary, U.S.A." *Journal of Fisheries Biology* 60:532-544.

Willenborg, P.M. 1999. *Potomac Electric Power Company 1998 Aquaculture Project*. Potomac Electric Power Company, Natural Resources Management Development, Washington, D.C. Jan.

Wilson, J., C.W. Osenberg, C.M. St. Mary, C.A. Watson, and W. J. Lindberg. 2001. "Artificial Reefs, the Attraction-Production Issue, and Density Dependence in Marine Ornamental Fishes." *Aquarium Sciences and Conservation* 3:95-105.

Wyda, J.C., L.A. Deegan, J.E. Hughes, and M.J. Weaver. 2002. "The Response of Fishes to Submerged Aquatic Vegetation Complexity in Two Ecoregions of the Mid-Atlantic Bight: Buzzards Bay and Chesapeake Bay." *Estuaries* 25(1):86-100.

Zabel, R.W., and J.G. Williams. 2002. "Selective Mortality in Chinook Salmon: What Is the Role of Human Disturbance?" *Ecological Applications* 12(1):173-183.

Zajac, R.N., and R.B. Whitlatch. 2001. "Response of Macrobenthic Communities to Restoration Efforts in an New England Estuary." *Estuaries* 24(2):167-183.

Zedler, J.B. 1993. "Canopy Architecture of Natural and Planted Cordgrass Marshes: Selecting Habitat Evaluation Criteria." *Ecological Applications* 3:136-138.

Zedler, J.B. 2001. "Introduction." Chapter 1 *in: Handbook for Restoring Tidal Wetlands*. J. B. Zedler (ed.). CRC Press, Boca Raton, FL.

Zedler, J.B., G.D. Williams, and J.S. Desmond. 1997. "Wetland Mitigation: Can Fishes Distinguish between Natural and Constructed Wetlands?" *Fisheries* 22:26-28.

Zieman, R.C., and R.T. Zieman. 1989. *The Ecology of the Seagrass Meadows of the West Coast of Florida: A Community Profile*. Biological Report 85(7-25). U.S. Fish and Wildlife Service, Washington, D.C. 155 pp.

Zimmerman, R.J., T.J. Minello, and L.P. Rozas. 2000. "Salt Marsh Linkages to Productivity of the Penaeid Shrimps and Blue Crabs in the Northern Gulf of Mexico." *In: Concepts and Controversies in Tidal Mash Ecology*. M.P. Weinstein and D.A. Kreeger (eds.). Kluwer Academic Publishers, Norwell, MA.

Zohar, Y., H. Perry, D. Eggleston, A. Hines, and R. Lipcius. 2003. *The Blue Crab,* Callinectes sapidus*: An Integrated Research Program of Basic Biology, Hatchery Technologies and the Potential for Replenishing Stocks*. Chesapeake Bay Fisheries Research Program Annual Report, presented at Research Project Symposium, March 24, pp 115-224.

# A
# APPENDIX A: TECHNICAL ASSISTANCE, TOOLS, AND ADDITIONAL INFORMATION

## A.1 Technical Information and Reports

*Atlantic Coastal Submerged Aquatic Vegetation: A Review of its Ecological Role, Anthropogenic Impacts, State Regulation, and Value to Atlantic Coastal Fish Stocks*. Stephan, C.D., and T.E. Bigford (editors). 1997. Atlantic States Marine Fisheries Commission Habitat Management Series #1. Available at: http://www.asmfc.org/Programs/Habitat/sav.pdf

*Bay Grasses (SAV) in Chesapeake Bay*. VIMS SAV Mapping Lab. 2002. Background information on SAV, program description, and data from the SAV Restoration Program at the Virginia Institute of Marine Science. Available at: http://www.vims.edu/bio/sav/

*Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis*. 2000, Chesapeake Bay Program, Annapolis Maryland. Available at: http://www.chesapeakebay.net/pubs/sav/index.html

*Compensating for Wetland Losses under the Clean Water Act*. National Research Council. 2001. Committee on Mitigating Wetland Losses, National Academy Press, Washington, D.C.

*Creating Freshwater Wetlands*. 1992. Hammer, D. Lewis Publishers.

*Draft National Artificial Reef Plan Revision*. National Marine Fisheries Service. 2002. Office of Constituent Services, National Marine Fisheries Service, Silver Spring, Maryland, February. Available at: http://www.nmfs.noaa.gov/irf/NARP.PDF

*European Artificial Reef Research Network*. General information about the aims and activities of the European Artificial Reef Research Network. Available at: http://www.soes.soton.ac.uk/research/groups/EARRN/main.html

*Evaluating Fishing Gear Impacts to Submerged Aquatic Vegetation and Determining Mitigation Strategies*. ASMFC Habitat Management Series # 5, Atlantic States Marine Fisheries Commission. 2000. Available at: http://www.asmfc.org/PUB/Habitat/Gear%20Impacts%20Report.pdf

*Fisheries Technologies for Developing Countries*. National Research Council. 1988. Office of International Affairs, National Research Council, National Academy of Sciences, Washington, D.C. Chapter 3 is called Artificial Reefs and Fish Aggregating Devices. Available at: http://books.nap.edu/books/0309037883/html/85.html#pagetop

*Lake Erie's Artificial Reef Program*. Ohio Sea Grant College Program, 1997. Ohio State University, Columbus, Ohio. Fact sheet about artificial reefs constructed in Lake Erie between 1984 and 1989 by the Ohio Sea Grant College Program. Contains information about why and how they were constructed in Lake Erie and the results of biological and economic research conducted on the artificial reefs. Available at: http://www.sg.ohio-state.edu/pdfs/fs-021.pdf

*Mitigation Technical Guidance for Chesapeake Bay Wetlands.* 1994. Eckles, S., T. Barnard, F. Dawson, T. Goodger, K. Kimidy, A. Lynn, J. Perry, K. Reisinger, C. Rhodes, and R. Zepp. Prepared for Living Resources Subcommittee, Chesapeake Bay Restoration Program, U.S. Environmental Protection Agency.

*Proceedings from the Second Annual Public Workshop for the SONGS Mitigation Project, February 27, 2002, San Clemente Community Center, San Clemente, California*. Reed, D., S. Schroeter, and M. Page (editors). 2002. Report submitted to the California Coastal Commission. April 3, 2002. Information about mitigation efforts for the San Onofre Nuclear Generating Station (SONGS), including the development and monitoring of an artificial kelp reef. Available at: http://www.coastal.ca.gov/energy/songs-workshop-mm2.pdf]

*Sport Fish Restoration Administrative Program. 2001 Artificial Reef Activities*. Description of the Sport Fish Restoration Program's involvement in artificial reef activities. Available at: http://www.gsmfc.org/wba_r.html

*Wetlands: Characteristics and Boundaries*. National Research Council. 1995. Committee on Characterization of Wetlands, National Academy Press, Washington, D.C. 308 p.

## A.2 Regional and National Agencies, Programs, and Organizations Related to Environmental Enhancements

*California Department of Fish and Game, Native Anadromous Fish and Watershed Branch:* http://www.dfg.ca.gov/nafwb/

*Chesapeake Bay Program Office:* http://www.chesapeakebay.net/fishpass.htm

*Connecticut River Watershed Council, Inc.*, One Ferry Street, Easthampton, MA, 01027.

The Conservation Fund: http://www.conservationfund.org

*Ducks Unlimited:* http://www.ducks.org/

*Everglades Trust*: http://www.saveoureverglades.org/index.html

*Great Lakes Fishery Trust*: http://www.glft.org

*Jefferson Land Trust*: http://www.saveland.org/

*Leetown Science Center, S.O. Conte Anadromous Fish Research Center:* http://www.lsc.usgs.gov/cafl/lsc-afl.htm

*Long Bay Artificial Reef Association*. Description of the Long Bay Artificial Reef Association program, including program history, reef locations, materials, and costs available at: http://www.lbara.com/index.html

National Conservation Training Center, training course in fish passageways and bypass facilities: http://www.nctc.fws.gov/catalog/fis2111.html

*National Fish Passage Program*, Fish and Wildlife Management Assistance, U.S. Fish and Wildlife Service: http://fisheries.fws.gov/FWSMA/FishPassage/index.htm

*The Nature Conservancy:* http://www.nature.org/

*San Diego Oceans Foundation. Artificial Reef Monitoring Program*. The Artificial Reef Monitoring Project uses research diving to deploy, monitor, and enhance artificial reefs in the San Diego area. A description of the project and monitoring methods are accessible at: http://www.sdoceans.org/arti_reef.htm

*Save the Dunes Council*: http://www.savedunes.org/

*Southern Appalachian Highlands Conservancy*: http://www.appalachian.org/

*Tampa Bay Estuary Program*: http://www.tampabaywatch.org/seagrass.htm

*Upper Colorado River Endangered Fish Recovery Program*: http://www.r6.fws.gov/coloradoriver/Index.htm

*Wilderness Land Trust*: http://www.wildernesslandtrust.org/

*World Wildlife Fund*: http://www.wwf.org/

## A.3 Regional and National Guidelines, Manuals, and Tools

*A Guide to Wetland Funcitonal Design*. 1992. Marble, A.D. Lewis Publishers, Boca Raton, FL.

*American Rivers Dam Removal Toolkit*. Available at: http://www.americanrivers.org (go to *Resource Center*, then *Dam Removal Toolkit*)

*An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement*. Undated. Interagency Workgroup on Wetland Restoration.

*California Salmonid Stream Habitat Restoration Manual, 3rd Edition*, California Department of Fish and Game, Inland Fisheries Division, Sacramento, CA. 1998. Available at http://www.dfg.ca.gov/nafwb/

*Fish Passage Barrier and Surface Water Diversion Screening Assessment and Prioritization Manual*, Washington Department of Fish and Wildlife, Olympia, WA. 2000 Available at: http://www.wa.gov/wdfw/hab/ahg/

*Fish Passage Design at Road Culverts*, Washington Department of Fish and Wildlife, Olympia, WA 1999. Available at: http://www.wa.gov/wdfw/hab/ahg/culverts.htm

*Fishway Guidelines for Washington State*, Washington Department of Fish and Wildlife, Olympia, WA. 2000. Available at: http://www.wa.gov/wdfw/hab/ahg/fishways.htm

*FishXing: Software and Learning Systems for Fish Passage Through Culverts:* http://www.stream.fs.feed/fishxing

*Guidelines for Evaluating Fish Passage Technologies*, American Fisheries Society Bioengineering Section, American Fisheries Society, Bethesda, MD. 2000. Available at: http://biosys.bre.orst.edu/afseng/fish_pass_comm.htm

*Guidelines for Minimizing Entrainment and Impingement of Aquatic Organisms at Marine Intakes in British Columbia*. Fedorenko, A.Y., Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2098. 1991.

*Guidelines for Salmonid Passage at Stream Crossings*, National Marine Fisheries Service, Santa Rosa, CA. 2000

*Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters*. Fonseca, M.S., W.J. Kenworthy, and G.W. Thayer. Decision Analysis Series No. 12, National Atmospheric and Atmospheric Administration, Coastal Ocean Program, Silver Spring, MD. 1998. Available at: http://shrimp.bea.nmfs.gov/library/digital.html]

*Habitat Manual for Use of Artificial Structures in Lakes and Reservoirs*. Southern Division American Fisheries Society Reservoir Committee. 2000. Available at: http://www.sdafs.org/reservor/manuals/habitat/main.htm

*Handbook for Restoring Tidal Wetlands*. Zedler, J.B. (ed.). 2001. CRC Press, Boca Raton, FL.

*Oregon Road/Stream Crossing Restoration Guide*. Oregon Department of Fish and Wildlife, Spokane, WA. 1999. Available at: http://www.4sos.org/wssupport/ws_rest/OregonRestGuide/

*Principles for the Ecological Restoration of Aquatic Resources*. Report EPA841-F-00-003. U.S. Environmental Protection Agency. Office of Water, Washington, D.C. 2000.

*Principles of Estuarine Habitat Restoration, Working Together to Restore America's Estuaries, Report on the RAE-ERF Partnership, Year One, September 1999*. Restore America's Estuaries-Estuarine Research Federation. 1999. Available at: www.estuaries.org.

*Restoration Planning, Guidance Document for Natural Resource Damage Assessment Under the Oil Pollution Act of 1990*, National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, Northwest Region, Seattle, WA. 1996. Available at: http://www.darcnw.noaa.gov/opa.htm.

*Stream Corridor Restoration, Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. GPO Item No. 0120-A. 1998.

*Submerged Aquatic Vegetation Policy*. Atlantic States Marine Fisheries Commission, ASMFC Habitat Management Series #3. 1997. Available at: http://www.asmfc.org/Programs/Habitat/savpolicy.pdf

## A.4 Ecosystem Valuation

American Agricultural Economics Association. Available at: http://www.aaea.org/

Association of Environmental and Resource Economists. Available at: http://www.aere.org

International Society for Ecological Economics. Available at: http://www.ecologicaleconomics.org/

Ecological Economics Discussion Group Archives. Available at: http://csf.Colorado.EDU/mail/ecol-econ/

The Land and Resource Economics Network. Available at: http://www.ems.psu.edu/MnEc/resecon/

Environmental Economics Distance Learning Course. Available at: http://www-agecon.ag.ohio-state.edu/class/AEDE531D/Sohngen/ae531d/

Resources for the Future (RFF). Available at: http://www.rff.org/

EPA Economy and Environment. Available at: http://www.epa.gov/oppe/eaed/home4.htm

National Center for Environmental Research and Quality Assurance (NCERQA). Available at: http://es.epa.gov/ncerqa

World Bank Environmental Economics and Indicators (EEI) – Environmental Valuation. Available at: http://wbln0018.worldbank.org/environment/EEI.nsf/all/Environmental+Valuation?OpenDocument

USDA Economic Research Service. Available at: www.ers.usda.gov/

U.S. Army Corps of Engineers Institute for Water Resources. Available at: www.iwr.usace.army.mil/

Monetary Measurement of Environmental Goods and Services. Available at: www.iwr.usace.army.mil/iwr/pdf/96r24.pdf

National Environmental Data Index (NEDI). Available at: http://www.nedi.gov/

ENVALUE: A Searchable Environmental Valuation Database. Available at: http://www.epa.nsw.gov.au/envalue/

Environmental Valuation Reference Inventory (EVRI). Available at: http://www.evri.ec.gc.ca/evri/

The Beijer Institute Discussion Papers. Available at: http://www.beijer.kva.se/publications/discussion/discussion_papers.html

NetEc. Available at: http://netec.wustl.edu/NetEc.html

Readings in the Field of Natural Resource & Environmental Economics. Available at: http://www.worldbank.org/nipr/readings/readings.pdf

National Library for the Environment Congressional Research Service Reports. Available at: http://cnie.org/NLE/CRS/

Agriculture Network Information Center. Available at: http://www.agnic.org/

NOAA/National Sea Grant Internet Resource for Coastal Environmental Economics. Available at: http://www.mdsg.umd.edu/Extension/valuation/

Committee on the Human Dimensions of Recreational Fisheries. Available at: http://lutra.tamu.edu/hdrfish.htm

Centre for the Economics and Management of Aquatic Resources. Available at: http://www.port.ac.uk/departments/economics/cemare/

Economy and Environment Program for Southeast Asia (EEPSEA) . Available at: http://www.eepsea.org/

Decision Making and Valuation for Environmental Policy. Available at: http://es.epa.gov/ncer/publications/workshop/nsf_epa.pdf

Valuing and Managing Ecosystems. Available at: http://yosemite.epa.gov/EE/epa/eerm.nsf/vwSER/D6952626EAA2253F85256A3F005E77DC?OpenDocument

Valuation and Environmental Policy. Available at: http://es.epa.gov/ncerqa_abstracts/grants/95/valuation/

Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP. Available at: www.ers.usda.gov/publications/AER778/

Innovation in the Valuation of Ecosystems: A Forest Application. Available at: http://es.epa.gov/ncerqa_abstracts/grants/95/valuation/valrusse.html

Developing Conjoint Stated Preference Methods for Valuation of Environmental Resources. Available at: http://es.epa.gov/ncerqa_abstracts/grants/95/valuation/valopalu.html

Ecosystem Valuation: Policy Applications for the Patuxent Watershed Ecological-Economics Model. Available at: http://es.epa.gov/ncerqa_abstracts/grants/96/deci/geoghega.html

Updating Prior Methods for Non-Market Valuation. Available at: http://es.epa.gov/ncerqa_abstracts/grants/96/deci/herriges.html

Monetary Measurement of Environmental Goods and Services. Available at: www.iwr.usace.army.mil/iwr/pdf/96r24.pdf

Valuing Urban Wetlands: A Property Pricing Approach. Available at: www.iwr.usace.army.mil/iwr/pdf/97r01.pdf

The Demand For Fishing Licenses and the Benefits of Recreational Fishing. Available at: http://www.rff.org/disc_papers/abstracts/9733.htm

Investments in Biodiversity Prospecting and Incentives for Conservation. Available at: http://www.rff.org/disc_papers/PDF_files/9614.pdf

Valuation of Biodiversity for Use in New Product Research in a Model of Sequential Search. Available at: http://www.rff.org/disc_papers/PDF_files/9627.pdf

Wetland Creation in the Kävlinge River Catchment, Scania, South Sweden. Available at: http://www.beijer.kva.se/publications/pdf-archive/sl0326.pdf

Empirical Cost Equations for Wetland Creation. Available at: http://www.beijer.kva.se/publications/pdf-archive/wetcost0915.pdf

Values of the Hadejia-Nguru Wetlands. Available at: http://www.geog.ucl.ac.uk/~jthompso/

The Economic Valuation of Mangroves: A Manual for Researchers. Available at: http://www.eepsea.org/publications/specialp2/ACF30C.html

The Economic Valuation of Tropical Forest Land Use Options: A Manual for Researchers. Available at: http://www.eepsea.org/publications/specialp2/toc.html

Evaluating Bintuni Bay: Some Practical Lessons in Applied Resource Valuation. Available at: http://www.eepsea.org/publications/specialp2/ACF2B0.html

Assessing Environmental Values: The Damage Schedule Approach. Available at: http://www.eepsea.org/publications/policybr3/ACF3B8.html

Sewage or Swimming? The Recreational Value of East Lake, Wuhan, China. Available at: www.eepsea.org/publications/policybr3/ACF3B2.html

Thailand's National Parks: Making Conservation Pay. Available at: www.eepsea.org/publications/policybr3/ACF3BC.html

Economic Analysis of Indonesian Coral Reefs. Available at: http://wbln0018.worldbank.org/environment/

The Economic Value of Wetlands: Wetlands' Role in Flood Protection in Western Washington. Available at: http://www.ecy.wa.gov/biblio/97100.html

Non-Market Economic User Values of the Florida Keys/Key West. Available at: http://cammp.nos.noaa.gov/

## A.5 Professional Societies

American Fisheries Society: http://www.fisheries.org/

American Fisheries Society Bioengineering Section: http://biosys.bre.orst.edu/afseng/Default.htm

Society for Ecological Restoration: http://ser.org/

Society of Wetlands Ecologists: http://www.sws.org/

Southern Division American Fisheries Society Reservoir Committee: http://www.sdafs.org/reservor/manuals/habitat/main.htm

## A.6 Scientific Journals

*Aquaculture*: Subscription information and access to back issues available at: http://www.fisheries.org/publications/journals/index.shtml

*Bulletin of Marine Science*: Subscription information and access to back issues available at: http://www.rsmas.miami.edu/bms/bms-intro.html

*Canadian Journal of Aquatic Sciences(Canadian Journal of Fisheries and Aquatic Sciences)*: Subscription information and access to back issues available at: http://www.nrc.ca/cgi-bin/cisti/journals/rp/rp2_desc_e?cjfas

*Conservation Biology*: Subscription information and access to back issues available at: http://www.blackwellscience.com/journals/biology/index.html

*Diseases of Aquatic Organisms*: Subscription information and access to back issues available at: http://www.int-res.com/journals/dao/index.html

*Ecological Applications*: Subscription information available at: http://www.esapubs.org/esapubs/default.htm

*Ecological Engineering*: Subscription information and access to back issues available at: http://www.elsevier.com/locate/ecoleng/

*Environmental and Resource Economics*: Subscription information and access to back issues available at: http://www.kluweronline.com/issn/0924-6460/

*Environmental Biology of Fishes*: Subscription information and access to back issues available at: http://www.kluweronline.com/issn/0378-1909/

*Environmental Management*: Subscription information and access to back issues available at: http://link.springer.de/link/service/journals/00267/

*Environmental Science and Policy*: Subscription information and access to back issues available at: http://www.elsevier.com/locate/envsci/

*Estuarine, Coastal and Shelf Science*: Subscription information and access to back issues available at: http://www.academicpress.com/ecss

*Estuaries*: Subscription information and access to back issues available at: http://estuaries.olemiss.edu/

*Fisheries*: Subscription information and access to back issues available at: http://www.fisheries.org/fisheries/fishery.shtml

*Fisheries Management and Ecology*: Subscription information and access to back issues available at: http://www.blackwell-science.com/fme

*Fishery Bulletin*: Subscription information and access to back issues available at: http://fishbull.noaa.gov/

*Hydrobiologia*: Subscription information and access to back issues available at: http://www.kluweronline.com/issn/0018-8158/

*Journal of Ecology*: Subscription information and access to back issues available at: http://www.blackwell-science.com/~cgilib/jnlpage.asp?Journal=jecol&File=jecol

*Journal of Experimental Marine Biology and Ecology*: Subscription information and access to back issues available at: http://www.elsevier.com/locate/jembe

*Journal of Fish Biology*: Subscription information and access to back issues available at: http://www.academicpress.com/jfb

*Journal of Great Lakes Research*: Subscription information and access to back issues available at: http://www.iaglr.org/jglr/journal.html

*Journal of Wetlands Ecology (Wetlands Ecology and Management)*: Subscription information and access to back issues available at: http://www.kluweronline.com/issn/0923-4861

*Journal of Wildlife Management*: Subscription information and access to back issues available at: http://www.wildlife.org/publications/journal.htm

*Marine Ecology Progress Series*: Subscription information and access to back issues available at: http://www.int-res.com/journals/meps/

*Marine Fisheries Review*: Subscription information and access to back issues available at: http://spo.nwr.noaa.gov/index.htm

*North American Journal of Aquaculture*: Subscription information and access to back issues available at: http://www.fisheries.org/publications/journals/index.shtml

*North American Journal of Fisheries Management*: Subscription information and access to back issues available at: http://www.fisheries.org/publications/journals/index.shtml

*Ocean and Coastal Management*: Subscription information and access to back issues available at: http://www.elsevier.com/locate/ocecoaman/

*Oecologia*: Subscription information and access to back issues available at: http://link.springer.de/link/service/journals/00442/

*Regulated Rivers: Research and Management*: Subscription information and access to back issues available at: http://www.interscience.wiley.com/jpages/0886-9375/
(Changed in 2002 to *River Research and Applications:* see below)

*Restoration Ecology*: Subscription information and access to back issues available at: http://www.blackwellscience.com/journals/ecology/index.html

*River Research and Applications*: Subscription information and access to back issues available at: http://www.interscience.wiley.com/jpages/1535-1459/

*Transaction of the American Fisheries Society*: Subscription information and access to back issues available at: http://www.fisheries.org/publications/journals/index.shtml

*Wetlands*: Subscription information and access to back issues available at: http://www.sws.org/wetlands/

*Wetlands Ecology and Management*: Subscription information and access to back issues available at: http://www.kluweronline.com/issn/0923-4861/

# B
# APPENDIX B: ANNOTATED BIBLIOGRAPHY

The following annotated bibliography of the recent literature on ecosystem restoration issues was compiled from EPRI's Quarterly Technical Newsletter. The bibliography covers the period January 2001 through March 2003. Papers are organized according to the following topics:

- General restoration issues
- Artificial reefs
- Fish passage and dam removal
- Hatchery supplementation or stocking
- Submerged aquatic vegetation
- Wetland restoration
- Miscellaneous restoration issues (e.g., beneficial use of dredged material, marine and freshwater protected areas, channel and riparian area restoration)

Each of the following papers, along with the historical literature on restoration-related topics, was reviewed as part of preparation of this report.

*General Restoration-Related Issues*

**The role of mitigation and conservation measures in achieving compliance with environmental regulatory statutes: lessons learned from Section 316 of the Clean Water Act.** Schoenbaum, T.J., and R.B. Stewart. 2002. *N.Y.U. Environmental Law Journal* 8: 237-331 – Authors conclude that recent claims by critics of mitigation measures that this longstanding practice is unlawful, or unsound as a policy matter, are baseless. They further conclude that the concept of mitigation should be embraced by EPA in its current Section 316(b) rulemaking: *In accordance with this analysis and conclusions in this article, and consistent with the Administration's commitment to regulatory flexibility and "common sense," EPA's section 316(b) rule should affirm that use of enforceable conservation measures that meet the section 316 criteria of environmental protection are lawful, and that such measures should be adopted when they offer economic and/or environmental advantages over source-based alternatives, including technology controls.*

**Taking the long view of ocean ecosystems: historical science, marine restoration, and the Oceans Act of 2000.** Craig, R.K. 2002. *Ecology Law Quarterly* 29: 649-705 – This paper discusses how declines in marine ecosystem function and sustainability led to the passage of the Oceans Act of 2000. The Ocean Act's overall goal for the U.S. marine regulation is "a coordinated, comprehensive, and long-range national policy for the responsible use and stewardship of ocean and coastal resources for the benefit of the U.S." New designated authority will be charged to regulate all uses of the ocean on an ecosystem basis. The author suggests that the goal of the new authority should be to restore each marine ecosystem to a particular historical level of productivity, which is based on historical studies. The primary means of achieving such restoration he further suggests should be a system of Marine Protected Areas (MPAs) and marine reserves, with the agency or agencies using marine zoning to designate 10 to 20 percent of the nation's marine waters off-limits to extractive uses. The author concludes that only by leaving large areas of the seas alone can we once again benefit from the ocean's full ecological – and economic – productivity.

**Quantifying natural resource injuries and ecological service reductions: challenges and opportunities.** Barnthouse, L.W., and R.G. Stahl, Jr. 2002. *Environmental Management* 30(1): 1-12 – This paper explores the scientific aspects of the Natural Resource Damage Assessment (NRDA) implementation and discusses conceptual and methodological relationships between NRDA and the much broader field of ecological risk assessment (ERA). The authors identify (1) scientific approaches drawn from ERA practice that could improve the NRDA approach, and (2) research needs and institutional changes that may improve the ability of the NRDA process to achieve its stated objectives.

**Methods of modifying habitat to benefit the Great Lakes ecosystem.** Kelso, J.R.M., and J.H. Hartig. 1995. National Research Council of Canada: http://pubs.nrc-cnrc.gc.ca/cgi-bin/rp/rp2_book_e?mlist4_145/ - This is a compilation of 47 methods of modifying habitat to benefit the Great Lakes ecosystem. The information is intended to raise awareness of Canada-U.S. progress toward restoration objectives in the Great Lakes and describes methods for rehabilitating, restoring, enhancing, mitigating, or preserving habitat.

**Spatial and temporal variation in estuarine fish and invertebrate assemblages: analysis of an 11-year data set.** Desmond, J.S., et al. 2002. *Estuaries* 25(4A): 552-569 – Protocols for monitoring wetland mitigation and restoration projects call for routine counts of animals, yet long-term spatial and temporal patterns are rarely examined. Analysis of monitoring data from three southern California estuaries spanning 11 years, four seasons, and multiple stations within the estuaries revealed differences in spatiotemporal patterns between fish and invertebrates. The authors conclude that the influence of spatial and temporal factors on estuarine invertebrates and fish communities should be considered in planning monitoring programs for wetland mitigation or restoration sites.

**The SER Primer on Ecological Engineering.** Society for Ecological Restoration Science & Policy Working Group. 2002. Can be downloaded from www.ser.org/ - Chapters include: definition of ecological restoration; attributes of restored ecosystems; explanation of terms; reference ecosystems; exotic species; monitoring and evaluation; restoration planning; relationship between restoration practice and restoration ecology; relationship of restoration to other activities; and integration of ecological restoration into a larger program.

**Reconciling ecosystem rehabilitation and service reliability mandates in large technical systems: findings and implications of three major U.S. ecosystem management initiatives for managing human-dominated aquatic-terrestrial ecosystems.** Roe, E., and M. van Eeten. 2002. *Ecosystems* 5: 509-528 – Authors assess the role of adaptive management and identify five areas of major innovation by which ecologists and the authorities that operate large water and hydropower systems attempt to reconcile the tensions between maintaining service reliability and promoting ecological rehabilitation.

**Functional variability of habitats within the Sacramento-San Joaquin Delta: restoration implications.** Lucas, L.V., et al. 2002. *Ecological Applications* 12(5): 1528-1547 – Comparative study of existing habitats is one way ecosystem science can elucidate and potentially minimize restoration uncertainties, by identifying processes shaping habitat functionality, including those that can be controlled in the restoration design.

**Assessing recovery in a stream ecosystem: applying multiple chemical and biological endpoints.** Adams, S.M., et al. 2002. *Ecological Applications* 12(5): 1510-1527 – The complexity of aquatic systems and their variable recovery dynamics suggest that no single measure is adequate for assessing aquatic ecosystem recovery and that a suite of chemical and biological endpoints is required for a more complete understanding of ecosystem dynamics and status during both recovery and the post-disturbance periods.

**Environmental Restoration – Ethics, Theory, and Practice.** Throop, W. (Editor). 2000. Humanity Books, Amherst, New York. 240 pp. – This book includes case studies, scientific and theoretical information on philosophical, scientific, legal, sociological, economic, and political environmental restoration issues.

**Landscape conservation and restoration: moving to the landscape level.** Hayes, D.J. 2002. *Virginia Environmental Law Journal* 21: 115-128 – David Hayes was Deputy Secretary in USDOI during the Clinton Administration. This paper is a speech he gave at the University of Virginia in 2000. He argues that a new movement that developed during the Clinton Administration that focused on new conservation and restoration efforts needs to be accelerated or advanced. Most importantly, that restoration needs to be focused at the landscape or watershed level.

**On the market for ecosystem control.** Johnston, J.S. 2002. *Virginia Environmental Law Journal* 21: 129-150 – This paper theorizes about alternate institutions for managing environmental controls. The author notes the limitations of the command and control approach and argues that the next generation of environmental and natural resource regulation will increasingly view the private development of public resources as an instrument for environmental restoration.

**The Economics of Nature: Managing Biological Assets**. G. Cornelius van Kooten and E.H. Bulte. 2000. Blackwell Publishers Inc. Malden, MA - This textbook covers the economics of ecosystem asset management. Chapters include consumer welfare measurement, producer welfare and aggregation of well being, resource rents and rent capture, valuing nonmarket benefits, evaluating natural resource policy, economic dynamics and renewable resource management, sustainable development and conservation, biological diversity and habitat, and endangered and threatened species.

**Public support for ecosystem restoration in the Hudson River Valley, USA.** Connelly, N.A., et al. 2002. *Environmental Management* 29(4): 467-476 – As hypothesized by the authors, the broad ecosystem restoration goals of the Hudson River Estuary Action Plan were more strongly supported than the corresponding specific implementation actions. The authors found that beliefs and past behavior were better explanatory variables than sociodemographic characteristics for explaining people's support for ecosystem restoration actions and willingness-to-pay for restoration and protection goals.

**Principles of Estuarine Habitat Restoration: Working Together to Restore America's Estuaries.** Restore America's Estuaries and the Estuarine Research Foundation. 1999. Report on the RAE-ERF Partnership – Year One – September 1999. www.estuaries.org and http://erf.org – Report discusses current state of estuaries in the U.S., their stresses, challenges in protection and restoration principles (planning, implementation, and design). Case example restoration projects presented include coastal wetlands in Maine, ecosystem restoration in Delaware Bay (Salem Project), the North Carolina Clean Water Trust Fund, and oyster restoration in Virginia.

**Resurrecting the dammed: a look at Colorado River restoration.** Cohn, J.P. 2001. *BioScience* 51(12): 998-1003 – A review of ongoing restoration efforts in the Colorado River Basin, one of the most regulated river systems in the U.S.

**Transferring economic values on the basis of an ecological classification of nature.** Ruijgrok, E.C.M. 2001. *Ecological Economics* 39: 399-408 – The author investigated whether it is possible to determine economic values for the elements of an ecological classification of nature, which can be transferred from one location to another. He concludes that his results indicate that the use of an ecological classification may offer economists new opportunities for transferring economic benefits within a limited geographic area.

**Valuing estuarine resource services using economic and ecological models: the Peconic Estuary System Study.** Johnston, R.J., et al. 2002. *Coastal Management* 30: 47-65.

**Business incentives for sustainability: a property rights approach.** Cerin, P., and L. Karlson. 2002. *Ecological Economics* 40: 13-22 – Authors propose a concept for trading of product life cycle (PLC) emission rights, based on property rights and transaction cost theories. Authors believe that this will provide economic incentives to take an increased responsibility for information flow as well as for product innovations.

**Design principles for ecological engineering.** Bergen, S.D. et al. 2001. *Ecological Engineering* 18: 201-210 – Successful ecological engineering will require a design methodology consistent with, if not based on, ecological principles. The authors identify five design principles to guide those practicing ecological engineering: (1) design consistent with ecological principles, (2) design for site-specific context, (3) maintain the independence of design functional requirements, (4) design for efficiency in energy and information, and (5) acknowledge the values and purposes that motivate design.

**Ecosystem structure, economic cycles and market-oriented conservation.** Crook, C., and R.A. Clapp. 2001. *Ecological Conservation* 28(3): 194-198 – Authors discuss and evaluate three strategies of the market-oriented use of natural resources and conclude that, at least for these three strategies, market-oriented mechanisms of conservation are often socially, economically, or ecologically unsustainable, and that proposals for market-oriented conservation should be approached with caution.

**Economic valuation of biodiversity: sense or nonsense?** Nunes, P., et al. 2001. *Ecological Economics* 39: 203-222 – This paper critically evaluates the notion and application of economic, monetary valuation of biological diversity, or biodiversity. The authors conclude that the empirical literature fails to apply economic valuation to the entire range of biodiversity benefits. Therefore, available economic valuation estimates should be regarded as providing a very incomplete perspective on, and at best lower bounds to, the unknown value of biodiversity changes.

*Artificial Reefs*

**Artificial reefs: a review of their design, application, management and performance.** M. Baine. 2001. *Ocean & Coastal Management* 44: 241-259 - A comprehensive literature review of artificial reefs, their design, application and management.

**Fish assemblages associated with artificial reefs of concrete aggregates or quarry stone offshore Miami Beach, Florida, USA.** Walker, B.K. et al. 2002. *Aquatic Living Resources* 15: 95-105 – Comparison of pre-deployment fish counts from the reef sites and neighboring hard bottom and jetty with counts from the same sites two years post-deployment indicate the artificial reefs increased both fish abundance and richness in the local area.

**Papers from the Seventh International Conference on Artificial Reefs and Related Aquatic Habitats.** Jensen, A.C. (Editor). *ICES Journal of Marine Science* 59 Supplement / *ICES Marine Science Symposia* 217 – Papers from a conference held in 1999 in Italy. The conference is held every four years to promote the exchange of information on the use of artificial habitats to enhance and manage marine and freshwater resources and protect the natural environment. Artificial habitats include benthic reefs, fish aggregating devices, and other man-made structures used to enrich aquatic environments, fishing opportunities, and populations of marine and freshwater plants and animals. This supplemental volume contains 55 papers that resulted from the conference. Some of the key papers of relevance to mitigating CWIS (Section 316b) impacts include:

1. **Artificial reefs of Europe: perspective and future.** Jensen, A.C. 2002. *ICES Journal of Marine Science* 59: S3-S13 – Artificial reefs have been in place in Europe for around 30 years. The majority now play a role in protecting value Mediterranean seagrass beds from trawl damage, and most aspire to a fisheries function.
2. **Larval productivity of a mature artificial reef: the ichthyoplankton of King Harbor, California, 1974-1997.** Stephens, J., Jr., and D. Pondella II. 2002. *ICES Journal of Marine Science* 59: S51-S58 – Do artificial reefs serve as productive

marine fish habitats (sources) or do fish assemblages of such reefs contribute little to the gene pool of succeeding generations (sinks)? Research at this southern California reef explicitly was designed to answer this question. The results indicate that the King Harbor breakwater represents a mature artificial reef and contributes to the reef fish larval pool of the bight, acting as a source rather than a sink.

3. **Assessment of out-of-kind mitigation success of an artificial reef deployed in Delaware Bay, USA.** Burton, W.H., et al. 2002. *ICES Journal of Marine Science* 59: S106-S110 – Results indicate that the artificial reef constructed to mitigate for harbor dredge impacts provides enhanced benthic secondary production per unit area over the lost habitat, but that total production does not equal what has been lost. The construction of this reef, while not completely effective in its intended mitigation, provides a benchmark by which to design and judge future mitigation efforts.
4. **Artificial reef design: void space, complexity, and attractants.** Sherman, R.L., et al. 2002. *ICES Journal of Marine Science* 59: S196-S200 – The potential for enhancing fish abundance, species richness, and biomass on artificial reefs was examined by manipulating structural complexity of small concrete reefs. Results further highlight the importance of structural complexity in artificial reef designed to enhance fish recruitment, aggregation, and diversity.
5. **Design considerations for an artificial reef to grow giant kelp (*Macrocystis pyrifera*) in Southern California.** Deysher, L.E., et al. 2002. *ICES Journal of Marine Science* 59: S201-S207 – As mitigation for estimated losses of kelp bed resources owing to the operation of the San Onofre Nuclear Generating Station (SONGS), Southern California Edison is building a 61-ha artificial reef to restore populations of the giant kelp. This paper discusses a design study on what substrates could be used, how large those substrates should be, how high they should be piled, and how they should be distributed.
6. **Effects of increased habitat complexity on fish assemblages associated with large artificial reef units (French Mediterranean coast).** Charbonnel, E., et al. 2002. *ICES Journal of Marine Science* 59: S208-S213 – Monitoring results confirm the prominent role of habitat complexity in relation to artificial reef design on diversity and abundance of fish assemblages.
7. **A quantitative framework to evaluate the attraction-production controversy.** Osenberg, C.W., et al. 2002. *ICES Journal of Marine Science* 59: S214-S221 – The authors discuss their model that incorporates the simultaneous effects of habitat augmentation, competition among reefs for larval settlers, and post-settlement density-dependence, and propose two experimental approaches for evaluating the effects of artificial reefs on local production of natural reefs.
8. **Evaluating artificial reef performance: approaches to pre- and post-deployment research.** Wilding, T.A., and M.D.J. Sayer. 2002. *ICES Journal of Marine Science* 59: S222-S230 – The utility of a baseline monitoring data set assembled pre-reef deployment to facilitate multi-parameter post-reef deployment comparisons is discussed.
9. **The use of coal fly ash in concrete for marine artificial reefs in the southeastern Mediterranean: compressive strength, sessile biota, and chemical composition.** Kress, N., et al. 2002. *ICES Journal of Marine Science* 59: S231-S237 – Results

show that, at least in the short term of 2 to 3 years, there is no environmental hazard to utilize coal fly ash in the construction of block units for artificial reefs.

**Use of artificial habitat structures in U.S. lakes and reservoirs: a survey from the Southern Division AFS Reservoir Committee**. Tugend, K.I., et al. 2002. *Fisheries* 27(5): 22- 27 – Of those states surveyed, 82% conducted some type of enhancement. In most states, 20% of water bodies received enhancement although respondents usually believed a larger portion of lakes and reservoirs (>40%) needed enhancement. Although about 60% of states reported evaluation of structures, evaluations usually were testing for differences in fish abundance or angler catch rates between habitat structures and control areas. Few studies documented effects of structures on fish recruitment or population size. Mores studies are needed to assess effects of habitat structures on recruitment and abundance of sport fish in lakes and reservoirs. An online habitat enhancement manual for more information on structures reported in this survey can be found at: www.sdafs.org/reservoir/manuals/habitat/Main.htm

**Reef habitats in the Middle Atlantic Bight: abundance, distribution, associated biological communities, and fishery resource use.** Steimle, F.W., and C. Zetlin. 2001. *Marine Fisheries Review*: 24 – This review provides a preliminary summary of information found on the relative distribution and abundance of reef habitat in the Bight, the living marine resources and biological communities that commonly use it, threats to this habitat and its biological resources, and the value or potential value of artificial reefs to fishery or habitat managers.

*Fish Passage or Dam Removal*

**The lower Susquehanna River: shad, eagles, and wildflowers.** Smith, R.K., and R.A. Bleistine. 2002. *Hydro Review* May 2002: SR12-SR15 – Paper discusses the success in restoring American shad to the Susquehanna River system via fish lifts and a fish stocking program. Shad passage has increased since 1985 (~1,500 fish) to nearly 200,000 fish in 2001. The fish lifts also serve as a source for female shad spawners from which eggs are gathered and distributed to hatcheries in Maryland and Pennsylvania.

**The complex decision-making process for removing dams.** Baish, S.K., S.D. David, and W.L. Graf. 2002. *Environment* 44(4): 21-31 – This paper is a summary manuscript of the information in the EPRI supported book published by the Heinz Center (EPRI Deliverable 1005396). The paper discusses the difficulties that must be addressed, and how they can be addressed, toward determining if a dam should or should not be removed.

**A preliminary review of NOAA's community-based dam removal and fish passage projects.** Lenhart, C.F. 2003. *Coastal Management* 31: 79-98 – This NOAA program supports habitat restoration projects, including 53 dam removal and fish passage projects from 1996 to 2002. This article provides a preliminary review of the biological benefits provided by the first 18 dam removal and fish passage projects supported between 1996 and 1999. These 18 projects improved access to over 160 km of river habitat for many anadromous fish species, especially river herring on the East Coast and salmonids on the West Coast.

**Short-term changes in channel form and macroinvertebrate communities following low-head dam removal.** Stanley, E.H., et al. 2002. *Journal of North American Benthological Society* 21(1): 172-187 – Pre- and post-dam removal studies at a low-head, run-of-river dam in the Barbazoo River, Wisconsin, found that within one year of removal, macroinvertebrate assemblages in formerly impounded reaches did not differ significantly from those in either the upstream reference site or in other impounded reaches below the dam site. Thus dam removal caused relatively small and transient geomorphic and ecological changes in downstream reaches, and apparently rapid channel development to an equilibrium form within the former impoundment. The authors attribute the muted changes to the relatively large channel size and the small volume of stored sediment available for transport following dam removal.

*Hatchery Supplementation or Stocking*

**The use of releases of reared fish to enhance natural populations: a case study on turbot *Psetta maxima* (Linné, 1758).** Stottrup, J.G., et al. 2002. *Fisheries Research* 59: 161-180 – Turbot were used as a model species to test if flatfish populations can be enhanced through regular release of hatchery fish to Danish waters. No evidence of displacement of the wild stock was found based on the findings of similar growth, similar size distribution in the later year classes, and constant ratio of reared and wild fish in the catches. The results suggest that release of reared turbot may result in an increase in fishery recruitment.

**Rapid evolution of egg size in captive salmon.** Heath, D.D., et al. 2003. *Science* 299 (14 March): 1738-1740 – Unintentional selection in captivity can lead to rapid changes in critical life-history traits that may reduce the success of supplementation or reintroduction programs.

**Maturation and fecundity of a stock-enhanced population of striped bass in the Savannah River Estuary, U.S.A.** Will, T.A., et al. 2002. *Journal of Fish Biology* 60: 532-544 – In 1990, GA-DNR began a hatchery-based, stock-enhancement program aimed at restoring a self-sustaining striped bass population in the Savannah River. The estimated annual survival of striped bass stocked in the river since 1990 is 35-45%, which has been high enough to substantially increase the numbers of striped bass in the river. Annual sampling surveys indicate that stocked fish constitute a majority (>75%) of the current population. Majority of fish in the river at present are young; however, as these young fish mature, egg production will likely increase and the density of striped bass eggs eventually will approach historic levels, provided suitable habitat and water quality are maintained.

**Homing of hatchery-reared American shad to the Lehigh River, a tributary to the Delaware River.** Hendricks, M.L., et al. 2002. *North American Journal of Fisheries Management* 22: 243-248 – Discusses the success from dam laddering and hatchery supplementation of American shad in this tributary of the Delaware River. Results also demonstrate that shad migrating into the river were not a random assortment of shad from the Delaware River population but based on homing specific to the Lehigh River. Results further suggest that efforts to restore American shad above dams should include some transplant strategy to expedite re-colonization.

**Optimization of North American flounder culture: a controlled breeding scheme**. Luckenbach, J.A., et al. 2002. *World Aquaculture* March 2002: 40-45 – Authors propose that restocking programs could positively impact flounder fisheries along the entire eastern seaboard. Developing biotechnology to enhance the mariculture of southern and summer flounder could benefit this effort and improve predictability and profitability of commercial operations.

**Aquaculture of paddlefish in the United States.** Mims, S.D. 2001. *Aquatic Living Resources* 14: 391-398 – Paper discusses the state-of-science for paddlefish culture in the Mississippi Basin.

**The culture of sturgeons in Russia: production of juveniles for stocking and meat for human consumption.** Chebanov, M., and R. Billard. 2001. *Aquatic Living Resources* 14: 375-381 – Paper describes the current state of science on sturgeon culture and stocking in Russia.

**Critically assessing stock enhancement: an introduction to the Mote Symposium.** Travis, J., et al. 1998. *Bulletin of Marine Science* 62(2): 305-311 – This 1998 paper is included because of its importance to EPRI's efforts to document the state-of-science for off-site mitigation/ restoration. This is the introductory paper to a 1998 symposium on the subject.

**Risk to genetic effective population size should be an important consideration in fish stock enhancement programs.** Tringali, M.D., and T.M. Bert. 1998. *Bulletin of Marine Science* 62(2): 641-659 – This paper discusses one of the key issues relative to hatchery supplementation; i.e., loss of genetic integrity.

**The economic performance of marine stock enhancement programs.** Hilborn, R. 1998. *Bulletin of Marine Science* 62(2): 661-674 – This 1998 paper is included because of its importance to EPRI's efforts to document the state-of-science for off-site mitigation/restoration. The author reviews the economic performance of stock enhancement programs around the globe. The author reviewed nine marine stocking programs for which biological or economic measures of success were available. Only one program, the Japanese chum salmon program, was a success. He discusses reasons for the economic failure of other programs and possible approaches for improving success.

*Submerged Aquatic Vegetation (SAVs) Restoration*

**Patterns in fish assemblages 25 years after major seagrass loss.** Vanderklift, M.A., and C.A. Jacoby. 2003. *Marine Ecology Progress Series* 247: 225-235 – This study conducted in Australia provided limited evidence for differences in fish assemblage related to presence or absence of seagrass. There were some differences in species composition, but many of the analyses were dominated by fine-scale spatial and temporal variation. Part of the variation in catches can be explained by spatial and temporal variation in the distribution of drift: drift seagrass was associated with a distinct assemblage of fishes: but was not restricted to beaches immediately adjacent to seagrass beds.

**Impact of habitat edges on density and secondary production of seagrass-associated fauna.** Bologna, P.A.X., and K.L. Heck, Jr. 2002. *Estuaries* 25(5): 1033-1044 – Secondary production was greater at edge than interior locations at test sites. These unexpected results suggest that differences in faunal densities and secondary production between edges and interiors of seagrass patches represent a potentially vital link in seagrass trophic dynamics.

**Eelgrass *Zostera marina* loss in temperate estuaries: relationship to land-derived nitrogen loads and effect of light limitation imposed by algae.** Hauxwell, J., et al. 2003. *Marine Ecology Progress Series* 247: 59-73 – In this paper the authors explicitly link changes in community structure of estuarine primary producers to measured nitrogen loading rates from watersheds to estuaries, and quantify the relationship between nitrogen load, annual dynamics of algal growth and *Zostera marina* productivity, and overall eelgrass decline at the watershed-estuarine scale in estuaries of Waquoit Bay, Massachusetts.

**Deterioration of eelgrass, *Zostera marina* L., meadows by water pollution in Seto Inland Sea, Japan.** Tamaki, H., et al. 2002. *Marine Pollution Bulletin* 44:1253-1258 – Eelgrass transplants at the outside of a meadow declined significantly, whereas those at the center were consistently well established. The authors hypothesize that flow rates at the outside were not enough to remove deposited sediments from the surface of eelgrass leaves and that the large amount of sediment deposition caused by water pollution and/or eutrophication also seemed to inhibit the survival of eelgrass at the outside edge of the transplanted meadow.

**Seed bank patterns in Chesapeake Bay eelgrass (*Zostera marina* L.): a Bay-wide perspective.** Harwell, M.C., and R.J. Orth. 2002. *Estuaries* 25(6B): 1196-1204 – The variety and importance of eelgrass seedbanks in the Chesapeake Bay relative to eelgrass conservation and restoration is discussed.

**Variations in eelgrass (*Zostera marina* L.) morphology and internal nutrient composition as influenced by increased temperature and water column nitrate.** Touchette, B.W., et al. 2003. *Estuaries* 26(1): 142-155 – In a mesocosm study (lab tanks), both increased temperature and increased nitrate led to declines in shoot density as well as decreased leaf and root production.

**Estuarine-open-water comparison of fish community structure in eelgrass (*Zostera marina* L.) habitats of Cape Cod.** Hunter-Thomson, K., et al. 2002. *Biological Bulletin* 203: 247-248.

**Effects of eelgrass habitat loss on estuarine fish communities of southern New England.** Hughes, J.E., et al. 2002. *Estuaries* 25(2): 235-249 – Fish abundance, biomass, species richness, dominance, and life history diversity decreased significantly along the gradient of decreasing eelgrass habitat complexity. Loss of eelgrass was accompanied by significant declines in these measures of fish community integrity. Ten of the 13 most common species collected from 1988-1996 showed maximum abundance and biomass in sites with high eelgrass habitat complexity. All but two common species declined in abundance and biomass with the complete loss of eelgrass.

**Modeling seagrass landscape pattern and associated ecological attributes.** Fonseca, M., et al. 2002. *Ecological Applications* 12(1): 218-237 – Paper discusses issues associated with decreasing seagrass habitat and the ecological services (e.g., water filtration, nursery habitat) provided by the seagrass resource. Authors discuss their attempts to develop a predictive model for seagrass bed coverage and ecological attributes of the bed, such as biomass and shoot density. Research was performed on seagrass habitat in Beaufort, North Carolina.

**The response of fishes to submerged aquatic vegetation complexity in two ecoregions of the mid-Atlantic Bight: Buzzards Bay and Chesapeake Bay.** Wyda, J.C., et al. 2002. *Estuaries* 25(1): 86-100 – The abundance, biomass, and species richness of the fish assemblage were significantly higher at sites that have high levels of eelgrass habitat complexity compared to sites that have reduced eelgrass habitat complexity or that have completely lost eelgrass. Abundance, biomass, and species richness at reduced eelgrass complexity sites also were more variable than at high eelgrass complexity habitats. Most species had greater abundance and were found more frequently at sites that have eelgrass. The replacement of SAV habitats by benthic macroalgae, which occurred in Buzzards Bay but not Chesapeake Bay, did not provide an equivalent habitat to seagrass. Nutrient enrichment-related degradation of eelgrass habitat has diminished the overall capacity of estuaries to support fish populations. [NOTE: this paper has fish density data.]

**Importance of shallow water habitats for demersal fishes and decapod crustaceans in Penobscot Bay, Maine.** Lazzari, M.A., and B. Tupper. 2002. *Environmental Biology of Fishes* 63: 57-66 – Authors found that the greater species diversity and higher abundance of epibenthic fishes and decapod crustaceans observed in vegetated habitats, particularly eel grass beds, compared with non-vegetated areas in Penobscot Bay conform to the hypothesis that increased habitat complexity results in increased species richness and abundance.

*Wetland Restoration*

**Characterization of wetland mitigation projects in Tennessee, USA.** Morgan, K.L., and T.H. Roberts. 2003. *Wetlands* 23(1) 65-69 – In a random sample of 50 projects, mitigation in the form of creation, restoration, enhancement, and preservation was used to replace 38 ha of jurisdictional wetlands destroyed. Over 104 ha of compensatory wetland mitigation were proposed for this loss; however, only 78 ha were present when each of the sites was delineated. Poor design resulting in improper hydrology and poor survival of planted stock was likely the primary cause of this reduced area. Wetland mitigation projects in Tennessee likely could be improved if greater emphasis was placed on design of the project, especially with regard to the hydrology of the site.

**Plant diversity, composition, and invasion of restored and natural prairie pothole wetlands: implications for restoration.** Seabloom, E.W., and A.G. van der Valk. 2003. *Wetlands* 23(1): 1-12 – The overall vegetative composition of restored wetlands was different from that of natural wetlands. Lower species richness, greater compositional variability, and lack of distinct flora in restored wetlands support the hypothesis that dispersal limitation is the primary cause of the differences between vegetation in restored and natural wetlands.

**Community metabolism during early development of a restored wetland.** McKenna, J.E., Jr. 2003. *Wetlands* 23(1): 35-50 – A restored wetland in upstate New York was examined to determine if ecological function (i.e., productivity), as well as biotic structure, was restored as compared with rates and conditions in a reference wetland. Typical wetland conditions and processes were found to develop quickly after restoration, but differences in biotic community structure indicate that observed rates of production and respiration at both sites were maintained by flow through different food-web pathways. Despite the relatively high process rates, any successional progress of the restoration site is expected to be slow.

**Habitat value of a developing estuarine brackish marsh for fish and invertebrates.**
Hampel, H., et al. 2003. *ICES Journal of Marine Science* 60: 278-289 – Studies in western Europe compared the utilization by nekton species of a natural mature marsh with a recently created developing marsh under similar conditions. A distinct difference in nekton community structure between the two marshes was observed, with biomass and densities of nekton higher in the natural marsh. The authors concluded that while creek morphology influences the abundance and species composition of visiting nekton, the age of a marsh and its maturity are believed to be the prime factors in determining the habitat function of creek systems of developing and mature marshes.

**Determining ecological equivalence in service-to-service scaling of salt marsh restoration.**
Strange, E., et al. 2002. *Environmental Management* 29(2): 290-300 – This paper describes habitat equivalency analysis (HEA), a habitat-based "service-to-service" approach for determining the amount of restoration needed to compensate for natural resource losses, and examines issues in its application in the case of salt marsh restoration.

**Natural and manipulated sources of heterogeneity controlling early faunal development of a salt marsh.** Levin, L.A., and T.S. Talley. *Ecological Applications* 12(6): 1785-1802 – This study used observations of natural variation and large-scale manipulative experiments to test the influence of vascular vegetation and soil organic matter on the rate and trajectory of macrofaunal recovery in a southern California created salt marsh. The most significant sources of heterogeneity in the recovering marsh were associated with site history and climate variation. Faunal recovery was most rapid in highly localized, organic-rich marsh sediments that were remnants of the historical wetland. The large spatial scale and multi-year duration of this study revealed that natural sources of spatial and temporal heterogeneity may exert stronger influences on faunal succession in California wetlands than manipulation of vegetation or soil properties.

**Flood Pulsing in Wetlands: Restoring the Natural Hydrobiological Balance.**
Middleton, B.A. (Editor). 2002. John Wiley & Sons, NY. www.wiley.com – Inclusive papers:

1. **The flood pulse concept in wetland restoration.** Middleton, B.A.
2. **Flood pulse and restoration of riparian vegetation in the American southwest.** Stromberg, J.C., and M.K. Chew
3. **The role of the flood pulse in ecosystem-level processes in southwestern riparian forests: a case study from the middle Rio Grande**. Ellis, L.M., et al.
4. **The role of flood pulse in maintaining *Boltonia decurrens*, a fugitive plant species of the Illinois River floodplain: a case history of a threatened species.** Smith, M., and P. Mettler.

5. **Conservation and restoration of semiarid riparian forests: a case study from the upper Missouri River, Montana**. Scott, M.L., and G.T. Auble.
6. **Implications of reestablishing prolonged flood pulse characteristics of the Kissimmee River and floodplain ecosystem.** Toth, L.A., et al.
7. **Flood pulsing in the regeneration and maintenance of species in riverine forested wetlands of the southeastern United States.** Middleton, B.A.

**Nutrient effects on the composition of salt marsh plant communities along the southern Atlantic and Gulf Coasts of the United States.** Pennings, S.C., et al. 2002. *Estuaries* 25(6B): 1164-1173 – Research results suggest that changes in nutrient input may lead to predictable changes in the composition of similar salt marsh plant communities across large geographic areas despite site to site variation in the abiotic environment.

**Tidal Wetland Restoration: Physical and Ecological Processes.** Goodwin, P., and A.J. Mehta (Editors). 2001. *Journal of Coastal Research* Volume SI(27) Winter 2001 – Special issue containing 14 papers on the theme. Inclusive papers are as follows:

1. **Tidal wetland restoration: an introduction.** Goodwin, P., et al. pages 1-6.
2. **Tidal salt marsh morphodynamics: a synthesis.** Friedrichs, C.T., and J.E. Perry. pages 7-37.
3. **Tidal wetland functioning.** Zedler, J.B., and J.C. Calloway. pages 38-64.
4. **Hydrodynamic and water quality processes in mangrove regions.** Struve, J., and R.A. Falconer. pages 65-75.
5. **Modeling of marshes and wetlands.** King, I.P. Pages 76-87.
6. **Subsurface flow and salinity response patterns in a tidal wetland marsh plain.** Greenblatt, M.S., and R.J. Sobey. pages 88-108.
7. **Mixing and circulation in wetlands.** Goodwin, P., and R.Z. Kamman. pages 109-120.
8. **Modeling muddy coast dynamics and stability.** Mehta, A.J., and R. Kirby. pages 121-136.
9. **Modeling muddy coast response to waves.** Rodriguez, H.N., and A.J. Mehta. pages 137-148.
10. **Restoring physical processes in tidal wetlands.** Williams, P. pages 149-161.
11. **Restoration of subsided sites and calculation of historic marsh elevations.** Krone, R.B., and G. Hu. pages 162-169.
12. **Creating tidal salt marshes in the Chesapeake Bay.** Perry, J.E., et al. pages 170-191.
13. **Tidal wetland restoration in The Netherlands.** Verbeek, H., and C. Storm. pages 192-202.
14. **Salt marsh restoration experience in San Francisco Bay.** Williams, P., and P. Faber. pages 203 –211.

**Wetland restoration thresholds: can a degradation transition be reversed with increased effort?** Lindrig-Cisneros, R., et al. 2003. *Ecological Applications* 13(1): 193-205 – Paper discusses the use of nitrogen fertilization on southern California wetland cordgrass to increase canopy, thereby providing protection and nesting habitat for the endangered light-footed clapper rail. Canopies were robust when urea was added; however, they reverted to short stature soon after fertilization ended.

**Use of restored small wetlands by breeding waterfowl in Prince Edward Island, Canada.** Stevens, C.E., et al. 2003. *Restoration Ecology* 11(1): 3-12 – Research demonstrates the ancillary benefits of wetland restoration.

**Growth and production of the mummichog (*Fundulus heteroclitus*) in a restored salt marsh**. Teo, S.L.H., and K.W. Able. 2003. *Estuaries* 26(1): 51-63 – Research conducted within one of PSEG's restored salt marshes coupled with the results of other studies on the feeding, movement, and habitat use of this species in the restored marsh indicate that the species has responded well to the restoration.

**Using gradients in tidal restoration to evaluate nekton community responses to salt marsh restoration.** Raposa, K.B., and C.T. Roman. 2003. *Estuaries* 26(1): 98-105 – Research in Massachusetts suggests that nekton demonstrate the greatest responses (assemblage and abundance), and that the most dramatic shift toward a more natural nekton assemblage will occur with restoration of severely restricted tidal salt marshes.

**Early responses of fishes and crustaceans to restoration of a tidally restricted New England salt marsh.** Raposa, K. 2002. *Restoration Ecology* 10(4): 665-676 – In this study, restoration induced rapid changes in the composition, density, size, and distribution of nekton species, but the authors believe additional monitoring is necessary to quantify longer-term effects of salt marsh restoration on nekton.

**Does facilitation of faunal recruitment benefit ecosystem restoration? An experimental study of invertebrate assemblages in wetland mesocosms.** Brady, V.J., et al. 2002. *Restoration Ecology* 10(4): 617-626 – Results suggest that facilitation of invertebrate recruitment (inoculating a restored wetland with vegetation/sediment plugs from a natural wetland and stocking of invertebrates) does indeed alter invertebrate community development and that facilitation may lead to a more natural community structure in less time under conditions simulating wetland restoration.

**Nutrient and freshwater inputs from sewage effluent discharge alter benthic and infaunal communities in a tidal salt marsh creek.** Twichell, S., et al. 2002. *Biological Bulletin* 203: 256-258.

**Ecological Restoration of Aquatic and Semi-Aquatic Ecosystems in the Netherlands (NW Europe).** Nienhuis, P.H., and R.D. Gulati (Editors). 2002. *Hydrobiologia* 478: - 12 papers listed below covering restoration of marine, brackish, and freshwater wetlands, riparian areas, and other freshwater areas:

1. **Ecological restoration of aquatic and semi-aquatic ecosystems in the Netherlands: an introduction.** Nienhuis, P.H., and R.D. Gulati. 2002. *Hydrobiologia* 478: 1-6.

2. **Ecological restoration in coastal areas in the Netherlands: concepts, dilemmas and some examples.** de Jonge, V.N., and D.J. de Jonge. 2002. *Hydrobiologia* 478: 7-28.
3. **Restoration of salt marshes in the Netherlands.** Bakker, J.P., et al. 2002. *Hydrobiologia* 478: 29-51 – A review of efforts to restore salt marshes in the Netherlands.
4. **Ecological rehabilitation of the lowland basin of the river Rhine (NW Europe).** Nienhuis, P.H., et al. 2002. *Hydrobiologia* 478: 53-72.
5. **Lakes in the Netherlands, their origin, eutrophication and restoration: state-of-the-art review.** Gulati, R.D., and E. van Donk. 2002. *Hydrobiologia* 478: 73-106.
6. **The restoration of fens in the Netherlands.** Lamers, L.P.M., et al. 2002. *Hydrobiologia* 478: 107-130.
7. **Towards a decision support system for stream restoration in the Netherlands: an overview of restoration projects and future needs.** Verdonschot, P.F.M., and R.C. Nijboer. 2002. *Hydrobiologia* 478: 131-148.
8. **Restoration of brook valley meadows in the Netherlands.** Grootjans, A.P., et al. 2002. *Hydrobiologia* 478: 149-170.
9. **Restoration of aquatic macrophyte vegetation in acidified and eutrophicated shallow soft water wetlands in the Netherlands.** Roelofs, J.G.M., et al. 2002. *Hydrobiologia* 478: 171-180.
10. **Restoration of coastal dune slacks in the Netherlands.** Grootjans, A.P., et al. 2002. *Hydrobiologia* 478: 181-203.
11. **A review of the past and present status of anadromous fish species in the Netherlands: is restocking the Rhine feasible?** De Groot, S.J. 2002. *Hydrobiologia* 478: 205-218 – The past, present, and future of restoration stocking of eight anadromous species inhabiting the Lower Rhine. The authors conclude that restocking programs should be considerably improved before noticeable success is to be met.
12. **SYNTHESIS: the state of the art of aquatic and semi-aquatic ecological restoration projects in the Netherlands.** Nienhuis, P.H., et al. 2002. *Hydrobiologia* 478: 219-233.

**Controls on fish distribution and abundance in temporary wetlands.** Baber, M.J., et al. 2002. *Canadian Journal of Fisheries & Aquatic Science* 59: 1441-1450 – Landscape processes (connectivity to permanent water bodies) predominantly influenced fish assemblages, although local processes (depth-hydroperiod) were also important.

**Hydrologic variability and the application of index of biotic integrity metrics to wetlands: a Great Lakes evaluation.** Wilcox, D.A., et al. 2002. *Wetlands* 22(3): 588-615 – Authors discuss how they developed and evaluated an index of biotic integrity for wetlands that could be used to categorize the level of degradation (or recovery).

**Hydrologic and chemical control of *Phragmites* growth in tidal marshes of SW Connecticut, USA.** Chambers, R.M., et al. 2002. *Marine Ecology Progress Series* 239: 83-91 – To control the growth of *Phragmites* in tidal marshes of management concern, both the feasibility and need for methods that increase flooding depth, frequency, salinity and/or sulfide concentrations should be considered.

**Breeding season bird use of restored wetlands in eastern Maryland.** Hotaling, N.E.M., et al. 2002. *Southeastern Naturalist* 1(3): 233-252 – Breeding season bird species richness, abundance, and diversity were evaluated in 21 restored wetlands and several associated habitats over two years. Restored emergent marshes were found to provide significant habitat for wetland birds, but benefits must be weighed against the loss of bird use in habitats converted to wetland.

**Section 404 wetland mitigation and permit success criteria in Pennsylvania, USA, 1986-1999.** Cole, C.A., and D. Shafer. 2002. *Environmental Management* 30(4) 508-515 – About 60% of the mitigation wetlands were judged as meeting their originally defined success criteria, some after more than 10 years. The permit process appears to have resulted in a net gain of almost 0.05 ha of wetlands per mitigation project. However, due to the replacement of emergent, scrub-shrub, and forested wetlands with open water ponds or uplands, mitigation practices probably led to a net loss of vegetated wetlands.

**Temperate freshwater wetlands: types, status, and threats.** Brinson, M.M., and A.I. Malvarez. 2002. *Environmental Conservation* 29(2): 115-133 – This review examines the status of temperate-zone freshwater wetlands and makes projections of how changes over the 2025 time horizon might affect their biodiversity.

**Approaches to coastal wetland restoration: northern Gulf of Mexico.** Turner, R.E., and W. Streever. 2002. SBP Academic Publishing, The Hague, The Netherlands. 147 pp – Techniques reviewed in the book for creating and restoring coastal wetlands include flooding former agricultural impoundments, backfilling canals, spoil bank removal, dredge material wetlands, and excavated wetlands.

**Fish-mediated nutrient and energy exchange between a Lake Superior coastal wetland and its adjacent bay.** Brazner, J.C. et al. 2002. *Journal of Great Lakes Research* 27(1): 98-111 – Results of research to quantify the flux of organisms, nutrients, and energy between freshwater coastal habitats and adjacent offshore waters. Results may have implications to the process of normalizing fish losses at CWIS to units of habitat restoration based on energy flux.

**Quantifying vegetation and nekton response to tidal restoration of a New England salt marsh.** Roman, C.T. et al. 2002. *Restoration Ecology* 10(3): 450-460 – Using a before-after-control-impact study, one year after restoring tidal flow to a marsh, vegetation and nekton rapidly approached that found in a control marsh. Nekton, in particular, in the restored marsh was observed to rapidly equal the density and richness of the unrestricted control marsh. This study provides a quantitative approach for assessing the response of vegetation and nekton to tidal restoration.

**Wetlands and Remediation II: Proceedings of the Second International Conference on Wetlands & Remediation**. Nehring, K.W., and S.E Brauning (Editors). 2002. Battelle Press, Columbus, OH and Richland, WA. 385 pp. – Papers from the 2nd International Conference on the subject held in 2001. Focused primarily on the remediation and restoration of contaminated wetlands through engineered and natural attenuation approaches. In addition, wetlands – both natural and constructed – are being increasingly used to treat contaminated water bodies and wastewater streams. 45 papers from the conference were accepted for publication. Papers address the topics of: Remediation of Wetlands Contamination; Wetlands for Wastewater Treatment; Wetlands Design, Construction, and Operation; and Wetlands Ecology and Restoration.

**Use of ecological services to scale compensation for wetlands impacts.** Weir, J.A., et al. 2002. Pages 303-311 *in* K.W. Nehring and S.E Brauning (Editors), Wetlands and Remediation II: Proceedings of the Second International Conference on Wetlands & Remediation, Battelle Press, Columbus, OH and Richland, WA – Through a collaborative approach with stakeholders, habitat equivalency analyses (HEA) were used to scale compensation options on an ecological service basis. This is contrary to the area-based ratio approach used in many ecological compensation projects. The selection of the preferred alternative centers around the ability to replicate lost ecological services, desire to fix a current environmental problem at the base, and confidence in planning-level costs.

**Riparian wetland function in channelized and natural streams.** Magner, J. 2002. Pages 363-370 *in* K.W. Nehring and S.E Brauning (Editors), Wetlands and Remediation II: Proceedings of the Second International Conference on Wetlands & Remediation, Battelle Press, Columbus, OH and Richland, WA. – Authors compared riparian wetland function in channelized and unchannelized streams and present results showing that natural channels with riparian wetlands provide both hydrologic and chemical attenuation in agricultural watersheds.

**Introduction to the Special Issue on Dike/Levee Breach Restoration of Coastal Marshes.** Simenstad, C.A. and R.S. Warren. 2002. *Restoration Ecology* 10(3) – 14 papers resulting from a 1999 conference on the subject sponsored by the Estuarine Research Federation. The purpose of this conference was to explore the potential and pitfalls of estuarine and coastal ecosystem restoration by breaching dikes and levees. This special issue includes the following papers:

1. **Estuarine and tidal wetland restoration in the United Kingdom: policy versus practice.** J. Pethick. 2002. *Restoration Ecology* 10(3): 431-437.
2. **Restoration of the Sieperda tidal marsh in the Scheldt estuary, The Netherlands.** R.H.M. Eertman et al. 2002. *Restoration Ecology* 10(3): 438-449.
3. **Quantifying vegetation and nekton response to tidal restoration of a New England salt marsh.** C.T. Roman et al. 2002. *Restoration Ecology* 10(3): 450-460.
4. **Using functional trajectories to track constructed salt marsh development in the Great Bay Estuary, Maine/New Hampshire.** P.A. Morgan and F.T. Short. 2002. *Restoration Ecology* 10(3): 461-473.
5. **Physical and functional responses to experimental marsh surface elevation manipulation in Coos Bay's south slough.** C. Cornu and S. Sadro. 2002. *Restoration Ecology* 10(3): 474-486.
6. **Floristic development patterns in a restored Elk River estuarine marsh, Grays Harbor, Washington.** R. M. Thom et al. 2002. *Restoration Ecology* 10(3): 487-496.

7. **Salt marsh restoration in Connecticut: 20 years of science and management.** Warren, R.S., et al. 2002. *Restoration Ecology* 10(3): 497-513 – Different time periods for restoring ecological functional equivalents to natural marshes for marsh flora and fauna are discussed. Overall, the state concludes that restoring tides will set degraded marshes on trajectories that can bring essentially full restoration, within two decades, of ecological functions.
8. **Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River Estuary, Oregon, USA.** A. Gray et al. 2002. *Restoration Ecology* 10(3): 514-526.
9. **Physical evolution of restored breached levee salt marshes in the San Francisco Bay Estuary.** P. Williams and M.K. Orr. 2002. *Restoration Ecology* 10(3): 527-542.
10. **Modeling habitat change in salt marshes after tidal restoration.** R.M.J. Boumans et al. 2002. *Restoration Ecology* 10(3): 543-555.
11. **A monitoring protocol to assess tidal restoration of salt marshes on local and regional scales.** H.A. Neckles et al. 2002. *Restoration Ecology* 10(3): 556-563.
12. **Restoration of freshwater intertidal habitat functions at Spencer Island, Everett, Washington.** C.D. Tanner et al. 2002. *Restoration Ecology* 10(3): 564-576.
13. **Hydraulic geometry: a geomorphic design tool for tidal marsh channel evolution in wetland restoration projects.** P.B. Williams et al. 2002. *Restoration Ecology* 10(3): 577-590.
14. **Drainage and elevation as factors in the restoration of salt marshes in Britain.** S. Crooks et al. 2002. *Restoration Ecology* 10(3): 591-602.

**Concepts and Controversies in Tidal Marsh Ecology**. M.P. Weinstein and D.A. Kreeger (Editors). Kluwer Academic Publishers, London, UK. 845 p. – A collection of 30 papers that discuss many of the key debated issues on the value of restored wetlands relative to natural systems. Questions discussed include: Do restored wetlands reach functional equivalency to "natural" systems; Are tidal marshes the "engine" that drives much of the secondary production in coastal waters; How is marsh restoration success measured? While all the papers in this book are key, the following are a few papers that summarize information on key technical issues in the overall debate on the value and function of wetlands:

1. **Salt marsh ecosystem support of marine transient species.** L.A. Deegan et al.
2. **Functional equivalency of restored and natural salt marshes.** J.B. Zedler and R. Lindig-Cisneros.
3. **The health and long-term stability of natural and restored marshes in Chesapeake Bay.** J.C. Stephenson et al.
4. **Initial response of fishes to marsh restoration at a former salt hay farm bordering Delaware Bay.** K.W. Able et al.
5. **Catastrophes, near-catastrophes, and the bounds of expectation: success criteria for macroscale marsh restoration**. M.P. Weinstein et al.

**Macroinvertebrate and fish populations in a restored impounded salt marsh 21 years after the reestablishment of tidal flooding.** Swamy, V., P.E. Fell, M. Body, M. Keaney, M. Nyaku, E. McIlvain, and A. Keen. 2002. *Environmental Management* 29(4): 516-530 – The State of Connecticut has restored tidal flow to many impounded salt marshes. One of these and the one most extensively studied is impoundment One in the Barn Island Wildlife Management Area in Stonington, Connecticut. The results obtained in this study and those of other restoring marshes at Barn Island indicate the full recovery of certain animal populations following the reintroduction of tidal flow to impounded marshes may require up to two or more decades. Furthermore, not only do different species recover at different rates on a single marsh, but the time required for the recovery of a particular species may vary widely from marsh to marsh, often independently of other species.

**Fifteen years of vegetation and soil development after brackish-water marsh creation**. Craft, C., et al. 2002. *Restoration Ecology* 10(2): 248-258 – Development of aboveground biomass and macro-organic matter (MOM) was dependent on elevation and frequency of tidal inundation. Aboveground biomass of *Spartina alterniflora*, which occupied low elevations along tidal creeks and was inundated frequently, developed to levels similar to the natural marsh within 3 years after creation. *S. cynosuroides,* which dominated interior areas of the marsh and was flooded less frequently, required 9 years to consistently achieve aboveground biomass equivalent to the natural marsh. Aboveground biomass of *S. patens*, which was planted at the highest elevations along the terrestrial margin and seldom flooded, never consistently developed aboveground biomass comparable with the natural marsh during the 15 years after marsh creation. MOM generally developed at the same rate as aboveground biomass. Wetland soil nutrient levels were estimated to take much longer (~30 years or more) to reach levels comparable to natural systems; however, development of the benthic invertebrate-based food web, which depends on organic matter enrichment of the upper 5 to 10 cm of soil, is estimated to take less time. The hydrologic regime (frequency of wetland flooding) of the "target" wetland should be considered when setting realistic expectations for success criteria of created and restored wetlands.

**A comparative assessment of genetic diversity among differently-aged populations of *Spartina alterniflora* on restored versus natural wetlands.** Travis, S.E., et al. 2002. *Restoration Ecology* 10(1): 37-42 – Findings indicate that restored populations of *S. alterniflora* maintain levels of genetic diversity comparable to natural populations, which should provide some measure of resistance against environmental disturbances.

**A comparison of created and natural wetlands in Pennsylvania, USA.** Campbell, D.A., et al. 2002. *Wetlands Ecology and Management* 10: 41-49 – To determine if differences existed between created and natural wetlands, the authors compared soil matrix chroma, organic matter content, rock fragment content, bulk density, particle size distribution, vegetation species richness, total plant cover, and average wetland indicator status in created and natural wetlands in Pennsylvania. Created wetlands ranged in age from 2 to 18 years. Results found that created wetlands still differed significantly from natural reference marshes; however, differences could be overcome or minimized with updated site selection practices, more careful consideration of monitoring period lengths, and, especially, a stronger effort to recreate wetland types native to the region should result in increased similarity between created and natural wetlands.

**Habitat use by fishes after tidal reconnection of an impounded estuarine wetland in the Indian River Lagoon, Florida (USA).** Poulakis, G.R., et al. 2002. *Wetlands Ecology and Management* 10: 51-69 – A 24.3-ha impoundment had been isolated from the Indian River

Lagoon for over 39 years. A 12-month study to determine habitat use by fishes after tidal reconnection and the implementation of Rotational Impoundment Management (a practice to minimize mosquito breeding) was performed. Within 15 weeks, significant increase in fish habitat use was observed (from 9 to 40 species). This study is the first to document the recovery of fish populations in a reconnected impoundment in the Indian River Lagoon area using both active and passive sampling techniques.

**Position paper on performance standards for wetland restoration and creation.** Society of Wetland Scientists. 2001. *Society of Wetland Scientists Bulletin* December 2001: 21-23 – The Society of Wetland Scientists recommends that (1) wetland restoration and creation project-planning documents should include clearly articulated performance standards that are based on the best available science and that reflect the structural and functional objectives of projects and (2) research linking performance standards to wetland function should be encouraged. Recommendations for performance standards are discussed.

**Declining biodiversity: why species matter and how their functions might be restored in Californian tidal marshes.** Zedler, J.B., et al. 2001. ***BioScience*** 51(12): 1005-1017 – This paper synthesizes data for tidal marshes of the California biogeographic region. Authors conclude that the California salt marsh plain is a model system for exploring the importance of diversity to restoration. Species-rich plantings enhanced the restoration site by increasing recruitment of native species, canopy complexity, biomass, and nitrogen accumulation. Recommendations for restoration practices are included.

**Movement and growth of tagged young-of-the-year Atlantic croaker (*Micropogonia undulatus* L.) in restored and reference marsh creeks in Delaware Bay, USA.** Miller, M.J., and K.W. Able. 2002. *Journal of Experimental Marine Biology and Ecology* 267: 15-33 – Both created creeks in a restored marsh and natural creeks in a reference marsh appeared to be utilized as a young-of-year habitat in a similar way during the summer and until egress out of the marshes during the fall; thus this restoration effort (off-site mitigation for PSEG's Salem Plant) has been successful in creating suitable habitat for Atlantic croaker.

**Effectiveness of compensatory wetland mitigation in Massachusetts, USA.** Brown, S.C., and P.L.M. Veneman. 2001. *Wetlands* 21(4): 508-518 – Paper principally discusses compensatory wetland mitigation in response to construction projects on existing wetlands. Numerous problems are noted related to design of wetlands, their maintenance, and their effectiveness with respect to those they are designed to replace. Most of these problems are regulatory in nature – lack of enforcement to ensure compliance with permit conditions.

**Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years.** Havens, K.J., et al. 2002. *Ecological Engineering* 18: 305-315 – Seven years after construction of a tidal marsh, the constructed marsh has progressed to a general level of function similar to that of nearby natural marshes. Some morphological differences remain, such as differences in community type ratios. Significant differences in habitat function remain in three areas: sediment organic carbon at depth, mature saltbush density, and bird utilization. Authors note that specific functions can be enhanced for fish utilization (more subtidal habitat) and for birds (more shrub habitat) depending on management priorities.

**Restoration principles emerging from one of the world's largest tidal marsh restoration projects.** Weinstein, M.P., et al. 2001. *Wetlands Ecology and Management* 9: 387-407 – Authors discuss the lessons learned and principles that are developing from one of the world's largest tidal wetland restoration projects that was conceived to offset the losses of fish to once-through cooling at a power plant (Salem) on Delaware Bay. The history of this project, and ultimately the restoration principles that emerge from it, are the subjects of this paper.

**Marsh terracing as a wetland restoration tool for creating fishery habitat.** L.P. Rozas and T.J. Minello. 2001. *Wetlands* 21(3): 327-341 – Terracing is a relatively new wetland-restoration technique used to convert shallow subtidal bottom to marsh. This method uses existing bottom sediments to form terraces or ridges at marsh elevation. Research examined the habitat value of terracing for fishery species at Sabine National Wildlife Refuge, Louisiana, in spring and fall 1999 by quantifying and comparing nekton densities in a 9-year-old terrace field and nearby reference area. Results indicated that terrace fields support higher standing crops of fishery species compared with shallow marsh ponds of similar size. Future restoration projects could include design changes to increase the proportion of marsh in a terrace field and enhance the habitat value of marsh terraces for fishery species.

**Diet composition of mummichogs, *Fundulus heteroclitus,* from restoring and unrestricted regions of a New England (U.S.A.) salt marsh.** James-Pirri, M.J., et al. 2001. *Estuarine, Coastal and Shelf Science* 53: 205-213 – The study provides evidence that tidally restored marshes can provide similar food resources as unrestricted marshes, in terms of consumption patterns of dominant marsh consumers, within the first year after restoration, before major shifts in dominant vegetation (i.e., from *Phragmites* to *Spartina* spp.) occur.

**Wetland restoration information:** see *Stages* 22(1) 2001 – The newsletter of the Early Life History Section of the American Fisheries Society (www.fisheries.org) describes many studies underway to evaluate the extensive marsh restoration project of Public Service Electric and Gas in Delaware Bay. Another web address for this section is: http://www.marine.rutgers.edu/rumfs/elh.htm. Check out the section on the Rutgers University Marine Field Station.

**The economic value of wetland services: a meta-analysis.** R.T. Woodward and Y-S. Wui. 2001. *Ecological Economics* 37: 257-270 - Using results from 39 studies, the authors evaluated the relative value of different wetland services, the sources of bias in wetland valuation, and the returns to scale exhibited in wetland values. While some general trends are emerging, the prediction of a wetland's value based on previous studies remains highly uncertain and the need for site-specific valuation efforts remains large. www.elsevier.com/locate/ecolecon

*Miscellaneous Restoration Topics*

**Small marine reserves may increase escapement of red drum.** Collins, M.R., et al. 2002. *Fisheries* 27(2): 20-24 – An experimental stock enhancement program was conducted in Port Royal Sound estuary, South Carolina, in which cultured red drum were released into a system of shallow tidal creeks that flow into the Colleton River. Stocked fish constituted nearly 18% of red drum collected nearly 1 year after stocking. Growth rates of stocked fish were similar to those of wild fish. It was found that while dispersal was substantial, many stocked fish stayed in the general area of release until reaching the age of maturity (~ age 3), when they left the estuary, and at all ages they were mixed with wild fish. This finding suggests that relatively small areas containing the appropriate suite of habitat types could be designated as marine reserves (no-take zones) in order to increase escapement of red drum, thus enhancing recruitment to the spawning stock. Establishing a system of these very small reserves in a number of estuaries would minimize interference with anglers while assisting recovery of red drum stocks, and perhaps enhancing stocks of other estuarine species as well.

**Post-project appraisals in adaptive management of river channel restoration.** Downs, P.W., and G.M. Kondolf. 2002. *Environmental Management* 29(4): 477-496 – Post-project appraisals (PPAs) can evaluate river restoration schemes in relation to their compliance with design, their short-term performance attainment, and their long-term geomorphological compatibility with the catchment hydrology and sediment transport processes. PPAs provide the basis for communicating the results of one restoration scheme to another, thereby improving future restoration designs. They also supply essential performance feedback needed for adaptive management, in which management actions are treated as experiments. PPAs allow river restoration success to be defined both in terms of the scheme attaining its performance objectives and in providing a significant learning experience.

**Freshwater protected areas: strategies for conservation.** Saunders, D.L., et al. 2002. *Conservation Biology* 16(1): 30-41 – Authors present three strategies for freshwater protected-area design and management: whole-catchment management, natural-flow maintenance, and exclusion of non-native species. These strategies are based on the three primary threats to fresh waters: land-use disturbances, altered hydrologies, and introduction of non-natives.

**A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific northwest watersheds.** Roni, P., et al. 2002. *North American Journal of Fisheries Management* 22: 1-20 – A hierarchical strategy is presented for maximizing restoration success – the strategy includes three elements: (1) principles of watershed processes, (2) protecting existing high-quality habitats, and (3) current knowledge of the effectiveness of specific techniques. Restoration techniques used in the Pacific Northwest are reviewed, and the authors conclude that existing research and monitoring is inadequate for all techniques reviewed, and additional, comprehensive physical and biological evaluations of most watershed restoration methods are needed.

**Riparian vegetation response to altered disturbance and stress regimes.** Shafroth, P.B., et al. 2002. *Ecological Applications* 12(1): 107-123 – Paper discusses study of the Bill Williams River (BWR) in western Arizona to understand dam-induced changes in channel width and in the areal extent, structure, species composition, and dynamics of woody riparian vegetation. Comparisons were made to the unregulated Santa Maria River (SMR) a tributary of the BWR. Aerial photographs showed that channels along the BWR narrowed, with most narrowing occurring after dam closure. The pattern of channel width change along the unregulated SMR was different, with less narrowing, in fact, some widening. Woody vegetation along the BWR was denser than that along the SMR. Patches dominated by exotic plants were marginally more abundant along the BWR, whereas the abundance of patches dominated by native plants was similar across rivers.

**Design and performance of a channel reconstruction project in a coastal California gravel-bed stream.** Kondolf, G.M., et al. 2001. *Environmental Management* 28(6): 761-776 – Wash out of a recently reconstructed reach required re-examination of stream restoration principles. Their examination casts doubt on several assumptions common in many stream restoration projects: that channel stability is always an appropriate goal; that channel forms are determined by flows with return periods of about 1.5 years; that a channel classification system is an easy appropriate basis for channel design; and that a new channel form can be imposed without addressing the processes that determine channel form.

**The concept of habitat diversity between and within ecosystems applied to river side-arm restoration.** Amoros, C. 2001. *Environmental Management* 28(6): 805-817 – Author proposed that since returning an ecosystem to a pristine state may not be realistic in every situation, the concept of habitat diversity should be followed to help decision makers in defining realistic restoration objectives. To maintain habitat diversity and enhance the long-term success of restoration, process-oriented projects should be preferred to species-oriented ones. The concept is applied to a Rhone River sector (France) where three terrestrialized side arms will be restored.

**Buffer zone versus whole catchment approaches to studying land use impact on river water quality.** L. Sliva and D.D. Williams. 2001. *Water Research* 35(14): 3462-3472 – Secondary data bases, GIS, and multivariate analysis tools were used to determine whether there was a correlation between water quality and landscape characteristics within three southern Ontario watersheds. Whole catchment and 100-m buffer zone influences on water quality over three seasons were compared. Forested land use appeared important in mitigating water quality degradation. The catchment landscape characteristics appeared to have slightly greater influence on water quality than the 100-m buffer.

**Response of macrobenthic communities to restoration efforts in a New England estuary.** R.N. Zajac and R.B. Whitlatch. *Estuaries* 24(2): 167-183 - Analysis of restoration efforts designed to increase tidal flushing by dredging in Alewife Cove, Connecticut, found positive results, but there was a lag in the ecological response of the system. Macrobenthic communities, in particular summer abundance patterns of selected species, provided an integrated assessment of ecological changes in the cove.

**Alternative Access Management Strategies for Marine and Coastal Protected Areas: A Reference Manual For Their Development and Assessment.** M.P. Crosby et al. (Editors). July 2000. U.S. Man and the Biosphere Program - Marine and coastal protected areas (MACPAs) are intended to protect and conserve critical habitats and serve as havens for endangered species. This document is a reference manual on the scientific, social, and economic procedures and benefits of management of these areas.

**Dependence of sustainability on the configuration of marine reserves and larval distance.** L.W. Botsford et al. 2001. *Ecology Letters* 4: 144-150 - Marine reserves hold promise for maintaining biodiversity and sustainable fishery management, but studies supporting them have not addressed a crucial aspect of sustainability: the reduction in viability of populations with planktonic larvae dispersing along a coastal habitat with noncontiguous marine reserves. Authors discuss the theoretical requisite size of reserves based on larval settlement processes.

**Patterns and predictions of population recovery in marine reserves.** S. Jennings. 2001. *Reviews in Fish Biology and Fisheries* 10: 209-231 - Marine reserves (no-take zones) are widely recommended as conservation and fishery management tools. This paper considers the factors that influence species recovery following marine reserve protection, describes patterns of recovery in numbers and biomass, and suggests how recovery rates can be predicted. Similar to the previous paper, the author notes that many reserves are very small in relation to the geographical range of fish and invertebrate populations.

**Detrimental effects of sedimentation on marine benthos: what can be learned from natural processes and rates?** Miller, D.C., et al. 2002. *Ecological Engineering* 19: 211-232 – Field and laboratory approaches in Delaware Bay were used to address two questions: (1) what rates and frequencies of sediment movement characterize natural events and (2) what rates and frequencies are detrimental to representative benthic species and functional groups? Results suggest that materials placement that is analogous to natural events should allow community responses to follow natural seasonal and successional trends and to exhibit minimal anthropogenic impacts.

**Editorial – Use of dredge materials for coastal restoration.** Costa-Pierce, B.A., and M.P. Weinstein. 2002. *Ecological Engineering* 19: 181-186 – Authors discuss and endorse the need to better understand and overcome past constraints and to accelerate the beneficial uses of uncontaminated dredged materials in order to dramatically reduce the need for disposal.

**Beneficial use of dredged material to enhance the restoration trajectories of formerly diked lands.** Weinstein, M.P., and L.L. Weishar. 2002. *Ecological Engineering* 19: 187-201 – The abundance of dredged materials from channel deepening projects that will occur nation-wide, the maintenance dredging of major ports, on-site construction and other projects provide a wealth of opportunities to combine dredging needs with coastal marsh rehabilitation and restoration.

**An assessment of long-term post-restoration water quality trends in a shallow, subtropical, urban hypereutrophic lake.** Ruley, J.E., and K.A. Rusch. 2002. *Ecological Engineering* 19: 265-280 – A major restoration effort was undertaken in 1983 that consisted of dredging and repair of the sewage infrastructure at this shallow urban lake located in Baton Rouge, Louisiana. Immediate improvements in water quality were observed following restoration: algal blooms and fish kills were eliminated for nearly a decade. Phosphorous has once again, however, reached pre-restoration levels, and nitrogen levels have decreased well below those observed during pre-restoration years.

**Innovative erosion control involving the beneficial use of dredge material, indigenous vegetation and landscaping along the Lake Erie shoreline.** Comoss, E.J., et al. 2002. *Ecological Engineering* 19: 203-210 – Beneficial use of dredge sediments to control shoreline erosion is discussed.