ELECTRIC POWER RESEARCH INSTITUTE

Do Power Plant Impingement and Entrainment Cause Changes in Fish Populations?

A Review of the Scientific Evidence

2011 TECHNICAL REPORT

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Report Summary

This report directly examines the peer-reviewed scientific evidence for the occurrence of changes, adverse or otherwise, as determined by researchers to fish and shellfish populations and to communities as a result of impingement and entrainment (I&E) mortality caused by power plant cooling water intake structures (CWISs).

Background

In 1972, Congress passed the Clean Water Act (CWA), and §316(b) applied directly to regulating the impacts of CWISs on aquatic life. Specifically, §316(b) requires the U.S. Environmental Protection Agency (EPA) to ensure that "*the location, design, construction and capacity of cooling water intake structures shall reflect the best technology available for minimizing adverse environmental impact.*" Since the CWA was passed, there have been several attempts to promulgate national regulations—most of which were later remanded as a result of legal challenges. On April 20, 2011, the EPA proposed a revised §316(b) Rule for existing power plants and other industrial facilities using cooling water (a combined Phase II and III regulatory action; FR 76(76)). Performance standards and monitoring requirements are proposed for reducing I&E mortality. The EPA expects that the proposed regulation will (FR 76(76), April 20, 2011) "*...minimize adverse environmental impacts, including substantially reducing the harmful effects of impingement and entrainment. As a result, the Agency anticipates this proposed rule would help protect ecosystems affected by cooling water intake structures and preserve aquatic organisms and the ecosystems they inhabit in waters used by cooling water intake structures at existing facilities.*" A final existing facility Rule is scheduled to be promulgated by July 27, 2012. The research reported on here examines whether there is scientific evidence to support the EPA's claim that there are, in fact, adverse environmental impacts to be reduced.

Objectives

- To examine whether published peer-reviewed scientific information supports the contention that power plant I&E mortality reduces fish populations and affects the ecosystem services that aquatic communities provide

Approach

The reviewed information includes (1) peer-reviewed literature reporting results of studies of impacts of I&E at power plants on fish populations, (2) peer-reviewed technical papers in the scientific literature relevant to demonstrating the linkage (if any) of I&E to reductions in the services provided by freshwater and marine ecosystems, (3) "blue-ribbon" commission reports such as the Pew Ocean Commission report and relevant National Research Council reports that discuss causes of fish population decline and marine ecosystem degradation, (4) the EPA's own reports on the condition and causes of degradation of coastal ecosystems, and (5) peer-reviewed papers and agency stock assessment reports documenting the causes of declines in marine and freshwater fish populations. The first two literature reviews directly examine the documentation of power plant CWIS impacts, while the latter three reviews approach the issue indirectly and retrospectively, that is, blue-ribbon commissions, the EPA, or fishery management agencies investigating causes of adverse environmental changes, specifically, the noted impacts of power plant CWISs.

Results

The diverse literature discussed in this report, including studies of both marine and freshwater ecosystems throughout North America and Europe, consistently identifies overfishing, habitat destruction, pollution, and invasive species as being the predominant causes of past and present impairment of fish populations and the ecosystems that support them. In those few cases where impacts of I&E mortality have been specifically investigated, such impacts have rarely been found. Although impacts due to I&E mortality have limited documentation in published studies, this absence does not prove that changes to fish populations and communities are not occurring or could never occur. The limited documentation of such impacts, however, after 40 years of operation of large power plants, some of which have been conducting extensive monitoring programs for several decades, provides substantial evidence that any such impacts are difficult to measure or are otherwise small compared to other impacts on fish populations and communities. Most important, there is little scientific evidence to support a conclusion that reducing I&E mortality via regulation of cooling water intakes will result in measurable improvements in recreational or commercial fish populations or ecological services.

Keywords

Adverse environmental impact	Entrainment
Clean Water Act Section 316(b)	Fisheries
Cooling water intake structures (CWIS)	Impingement

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Section 1: Introduction

In 1972, Congress passed the Federal Water Pollution Control Act Amendments, 33 U.S. C. §§ 1251 et seq., (popularly known as the Clean Water Act or CWA), which included a provision (§ 316(b)) authorizing the United States Environmental Protection Agency (EPA) to regulate cooling water intake structures (CWIS). Specifically, §316(b) requires that "*...the location, design, construction and capacity of cooling water intake structures shall reflect the best technology available for minimizing adverse environmental impact.*" In 1976, EPA issued a rule implementing §316(b); however, that rule was later suspended on procedural grounds. Following suspension of the rule, EPA issued draft guidance advising permit writers how to implement § 316(b) on a case-by-case basis during NPDES permitting. Both the 1976 rule and EPA's subsequent guidance focused on the potential impingement and entrainment (I&E) of fish and shellfish to cause adverse environmental impact.

In 1993, a coalition of environmental groups sued EPA for failure to promulgate national standards implementing §316(b) requirements. As a result, EPA entered into a consent decree to develop in phases final regulations for both existing and new facilities that use CWIS. A Phase I Rule for new facilities was issued in 2001. The "Phase I" Rule essentially requires closed-cycle cooling systems or comparably performing intake technologies as best technology available (BTA) to minimize adverse environmental impact (AEI). In 2004, EPA promulgated a Phase II Rule to implement regulations for existing power plants that withdraw > 50 million gallons per day (MGD) of cooling water. In 2006, EPA finalized a Phase III Rule for existing power plants withdrawing < 50 MGD and all other industrial facilities that use cooling water. Both regulations were subsequently challenged and later remanded or withdrawn by the Agency.

On April 20, 2011, EPA proposed a revised §316(b) Rule for existing power plants and other industrial facilities using cooling water (a combined Phase II and III regulatory action)(FR 76(76). Performance standards and monitoring requirements are proposed for reducing I&E mortality. EPA says that the proposed regulation will:

"...minimize adverse environmental impacts, including substantially reducing the harmful effects of impingement and entrainment. As a result, the Agency anticipates this proposed rule would help protect ecosystems affected by cooling water intake structures and preserve aquatic organisms and the ecosystems they inhabit in waters used by cooling water intake structures at existing facilities."

EPA plans to sign the final rule by July 27, 2012.

EPA included a detailed discussion of the environmental benefits of reducing I&E in Chapter A6 of its Regional Benefits Assessment for the 316(b) Phase III rule (USEPA 2006). According to this discussion, reducing I&E losses would be expected to "*...contribute to the enhanced environmental functioning of affected waterbodies and associated ecosystems.*" Two specific benefits of this "*enhanced environmental functioning*" were identified by EPA:

- Contribution to the recovery of damaged fish populations
- Contribution to restoring or preserving the services provided by saltwater and freshwater ecosystems

With respect to the recovery of damaged fish populations, EPA claimed that I&E may have contributed to the depletion of a large number of freshwater and marine fish populations. With respect to restoration/preservation of ecosystem services, EPA identified nine ecological services that could potentially be disrupted by I&E, these include:

- Decreased numbers of ecological keystone, rare, sensitive, or threatened and endangered species;
- Decreased numbers of popular commercial and recreational fish species that are not fished, perhaps because the fishery is closed;
- Increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E (I&E may also help remove some exotic or disruptive organisms);
- Disruption of ecological niches and ecological strategies used by aquatic species;
- Disruption of energy transfer through the food web;
- Decreased local biodiversity;
- Disruption of predator-prey relationships;
- Disruption of age class structures of species; and
- Disruption of natural succession processes.

The purpose of this report is to evaluate the scientific validity of the above claims through a review of the peer-reviewed scientific literature on fish population depletion and on ecosystem services. The reviewed technical papers includes (1) peer-reviewed literature reporting results of studies of impacts of I&E at power plants on fish populations, (2) peer-reviewed technical papers in the scientific literature relevant to demonstrating the linkage (if any) of I&E to reductions in the services provided by freshwater and marine ecosystems, (3) "blue-ribbon" commission reports such as the Pew Ocean Commission (2003) report and relevant National Academy of Sciences Reports that discuss causes of fish population decline and marine ecosystem degradation, (4) EPA's own reports on the condition and causes of degradation of coastal ecosystems, and (5) peer-reviewed papers and agency stock assessment reports documenting the causes of declines in marine and freshwater fish populations. The first two literature reviews directly examine the documentation of power plant CWIS impacts while the latter three reviews approach the issue indirectly; i.e., have blue-ribbon commissions, EPA or fishery management agencies specifically noted impacts of power plant CWIS and have proposed or posited actions to mitigate them.

The issue is not whether I&E could *potentially* have adverse environmental impacts, but on whether any such impacts have been shown to occur over the nearly 40 years since the enactment of CWA §316(b). This report emphasizes causes that are potentially responsible for changes in fish populations and communities that have occurred over this 40-year period. Large-scale, permanent habitat modifications such as damming and channelization of rivers have had clear and obvious impacts on many estuarine and freshwater fish species. However, most of these modifications occurred prior to the 20th century. Although they provide an important historical perspective on the adverse impacts of human activities on fish populations, habitat alterations that occurred more than 100 years ago are unlikely to be responsible for more recent adverse changes in fish populations.

This report complements a previous effort conducted for EPRI by the Oak Ridge National Laboratory (EPRI 2003) which also examined the relationship between power plant I&E and fish population effects. This previous effort was more focused on the *possible* relationship between the volume of water withdrawn by a water intake and the status of fish populations and aquatic communities in the source water body. It attempted to evaluate the existence of a dose-response relationship. It also looked at all forms of water withdrawal (e.g., hydropower, municipal water supply, irrigation) in addition to those by power plants. The analyses and reviews conducted in that EPRI (2003) study did not find a compelling dose-response relationship between volume of water withdrawn and status of fish populations when habitat is not reduced by the withdrawal. Evidence from multiple sources reviewed by EPRI (2003) suggested that the dose-response relationship is a horizontal line with a slope of zero and high variability.

Section 2: Peer-Reviewed Studies of Adverse Impacts of I&E

Even prior to the 1972 passage of the CWA, concerns had been raised by both government agencies and nongovernmental organizations about the potential impacts of impingement and entrainment (I&E) on fish populations (Barnthouse et al. 1984). Despite these concerns, in the more than 40 years since they were originally raised relatively few studies of adverse impacts of I&E on fish populations have been published in the peer-reviewed scientific literature. The best-known of these studies were published as American Fisheries Society Monographs.

2.1 Connecticut River and Hudson River Monographs

The Connecticut River Ecological Study, which documented monitoring and assessment studies performed during construction and early operation of the Connecticut Yankee plant on the lower Connecticut River, was originally published in 1976. An update reproducing the original monograph and documenting ecological studies performed in the river after the completion of the original study was published in 2004 (Jacobson et al. 2004). The Connecticut River study was designed in the mid-1960s, prior to the emergence of I&E as a major regulatory issue, at a time when thermal discharges were expected to be the most important causes of adverse impacts on receiving water bodies. Hence, much of the study focused on impacts of Connecticut Yankee's thermal plume. Entrainment monitoring was conducted, however, and the study estimated that 4% of fish eggs and larvae passing by the plant could be entrained. The study authors drew no inferences concerning the impacts of entrainment on adult populations because of lack of information concerning: (1) the natural mortality rates of susceptible life stages and (2) the carrying capacity of the river system.

The updated study (Jacobson et al. 2004) documented results of 37 years of monitoring and research conducted following the completion of the original study, including the entire remaining period of operation of Connecticut Yankee, which ceased commercial operation in 1996. Major changes in the Connecticut River fish community documented in this monograph include decreased abundance of native alosids (alewife, blueback herring, and American shad), increased abundance of alosids native to mid-Atlantic and southern rivers (gizzard shad and hickory shad), and a shift in the relative abundance of different catfish species. None of these changes were attributed to the operation of

Connecticut Yankee, and the authors concluded that there is no evidence that plant operations had any long-term impact on the ecology of the lower Connecticut River:

"...when evaluated some 30 years later, in the context of significant improvements in analytical tools, the original Study conclusions regarding the level of impact have been largely confirmed. There is no evidence of any long-term impact of the operation of CY on the ecology of the lower Connecticut River."

Environmental research and assessment studies addressing impacts of I&E at multiple power plants located on the lower Hudson River were documented in a 1988 monograph (Barnthouse et al. 1988a). In contrast to the Connecticut River study, the emphasis of the Hudson River studies was on quantifying the impacts of I&E on populations of juvenile and adult fish. Species addressed included striped bass, white perch, Atlantic tomcod, bay anchovy, alewife, blueback herring, and American shad. Most of the data used in the quantitative assessments, however, was collected over a 3-year period (1974-1976) when the power plants (Indian Point Units 2 and 3, Bowline Point Units 1 and 2, and Roseton Units 1 and 2) that were the focus of the assessments had just begun operation. Hence, most of the papers in the monograph deal with either estimated impacts on individual year classes or potential long-term impacts on adult populations. The estimated reductions in individual year classes (Boreman et al. 19888; Barnthouse and Van Winkle 1988) ranged approximately from 10% - 20%. These mortality rates, although by no means negligible, were judged by both agency and utility scientists to be substantially smaller than mortality rates imposed by fishermen on many harvested species (Barnthouse et al. 1988b). The river-wide monitoring program that provided the data used in these studies has continued through the present, and subsets of the data have been used in several peer-reviewed publications (Barnthouse et al. 2003a, Strayer et al. 2004, Heimbuch 2008, Barnthouse et al. 2009), however, no publications have used these data to address long-term impacts of I&E at Hudson River power plants.

2.2 Other Studies Using Population Models and Site-specific Data

Jensen (1982) used conventional fishery assessment models to quantify the impact of I&E at the Monroe power plant on the yellow perch stock in the western basin of Lake Erie. He concluded that E&I at Monroe would cause only a 2%-3% impact on the equilibrium biomass of the yellow perch population. In contrast, fishing this population at the level associated with maximum sustainable yield (annual harvesting of 35% of the population) would reduce the equilibrium biomass of the population by 50%. In a related paper, Jensen et al. (1982) used the same types of models to quantify impacts of I&E at 15 power plants on alewife, rainbow smelt, and yellow perch populations in Lake Michigan. The authors concluded that impacts of I&E on the biomass of all three species were small: 0.28% for yellow perch, 0.76% for rainbow smelt, and 2.86% for alewife.

Lorda et al. (2000) used a model of the Niantic River winter flounder population to evaluate combined impacts of I&E and fishing on future trends in the abundance of this population. The model was parameterized using 25 years of data on entrainment and impingement of winter flounder at the Millstone Nuclear Power Station and a similar time series of data on the abundance and age structure of the population of winter flounder that spawns in the Niantic River. Lorda et al. (2000) found that the influence of fishing on the abundance of this population was much larger than the influence of I&E. According to these authors, by 1995 fishing had reduced the biomass of the Niantic River winter flounder spawning stock by nearly 90%, from an un-fished level of 120,000 lbs to less than 15,000 lbs. Because of the high level of fishing mortality, reducing entrainment at Millstone by 50% would increase the spawning population by only about 9%. As discussed below (Section 7.4), the conclusion of Lorda et al. (2000) concerning fishery impacts is consistent with the findings of the National Marine Fisheries Service, which has concluded that the Southern New England-Mid Atlantic winter flounder stock, of which the Niantic River population is a component, has been severely depleted by overfishing.

Barnthouse et al. (2003b) used a combination of long-term monitoring data and population-level assessment models to address impacts of 25 years of operation of the Salem Generating Station on fish populations and communities in the Delaware Estuary. Trends analysis found no evidence that I&E at Salem had caused reduction in either the diversity of the Delaware Estuary fish community or the abundance of key fish populations. Model analyses showed that the impacts of I&E on weakfish and other harvested fish populations was small compared to the impacts of fishing. Although finding no evidence for impacts caused by Salem's operations, Barnthouse et al. (2003b) found strong evidence that many Delaware Estuary fish populations had increased in abundance following improvements in water quality and reductions in harvests that occurred between 1975 and 1998.

Henderson et al. (1984) used 11 years of data on impingement of sand smelt at the Fawley Power Station, Hampshire, UK to assess impacts of age-selective impingement on the age distribution of local sand smelt population. These authors found that impingement had no measurable effect, and concluded that the operation of Fawley Power Station had no significant effect on the long-term stability of this population.

Perry et al. (2003) used population models to evaluate impacts of I&E at six Ohio River power plants on local populations of bluegill, freshwater drum, emerald shiner, gizzard shad, sauger, and white bass. The model was parameterized using annual estimates of (1) I&E from each power plant and (2) the abundance of the target populations in the navigational pools on which the plants are sited. Given available data concerning year-to-year variability in the abundance of these populations, the model was used to determine whether, if there had been no I&E, a measurable increase in the abundance of each population could have occurred. Results indicated that measurable increases in the abundance of 6 of the 22 local populations examined might have been measurably higher, if there had been no I&E. However, the authors noted that these predicted increases were small compared to changes caused by habitat modification, water quality, floods, droughts, and temperature extremes.

Heimbuch et al. (2007a) used population models to assess impacts of entrainment and impingement at the Poletti Power Project on winter flounder and Atlantic menhaden populations in the New York/New Jersey Harbor Estuary and Long Island Sound. These authors found reductions in abundance due to I&E of only 0.09% for winter flounder and 0.01% for Atlantic menhaden as a result of entrainment and impingement at Poletti. As discussed in Section 4 below, the impacts of fishing on these populations is estimated to be several orders of magnitude higher than these values.

Nisbet et al. (1996) modeled the potential impact of entrainment of fish larvae by the San Onofre Nuclear Generating Station (SONGS) on fish populations in the Southern California Bight. They concluded that, depending on assumptions made concerning the strength of density-dependence, the standing stock of local queenfish and white croaker populations could be reduced by about 13% and 6%, respectively. No estimates of impacts of fishing on these populations are available.

Ehler et al. (2003) used equivalent adult models and an empirical transport model (ETM) to evaluate impacts of entrainment at the Diablo Canyon Power Plant on rockfish and kelpfish populations in the vicinity of the plant. The assessment used long-term data on entrainment on the local abundance of larval and adult fish. Based on relatively high station-related mortality predicted by the ETM and a decline in abundance following start-up of the plant, the authors concluded that entrainment could have had an adverse impact on local clinid kelpfish populations. Ehler et al. (2003) had no information concerning other influences on clinid kelpfish, because these fish are not harvested and little is known about their life history.

White et al. (2010) recently challenged the assumptions underlying the assessment approach used by Ehler et al. (2003) and others to addressed impacts of entrainment at California coastal power plants on benthic fish populations that produce pelagic larvae that are susceptible to entrainment. White et al. (2010) explicitly simulated the dispersal and settlement processes of larvae spawned in the vicinity of cooling water intake structures. These authors found that because of density-dependent post-settlement mortality, entrainment of larvae generally had only minor effects on adult population density. Compared to the spatially explicit model used by these authors, the approach used by Ehler et al. (2003) and others consistently overstated entrainment impacts. White et al. (2010) found that entrainment of larvae could only threaten the persistence of a local population if adult densities were already reduced to low levels by other stressors.

2.3 Studies Comparing Equivalent Adult Losses to Commercial Landings

Other authors have addressed adverse impacts of I&E by comparing estimates of impingement and entrainment losses, expressed as equivalent adults, to commercial fishery landings. As discussed in EPRI (2004), equivalent adult estimates are often highly uncertain, because of the difficulty of accurately estimating mortality rates of early life stages of fish. Moreover, equivalent adult estimates are inherently conservative, because they do not account for density-dependence of early life stage mortality. In addition, this simple comparative approach involves neither long-term trends analysis of population-specific data nor explicit modeling of population dynamics. For this reason, the equivalent adult approach is best viewed as a screening approach suitable for identifying situations in which an adverse impact might occur. Without other supporting information, it cannot demonstrate whether or not an adverse impact due to I&E is occurring or has occurred.

Saila et al. (1997) used equivalent adult models to address impacts of I&E on pollock, red hake, and winter flounder impinged and entrained at the Seabrook Station. These authors found that for the years 1990-1995 the maximum number of equivalent adult pollock impinged and entrained at Seabrook in any year was 136 fish, and the maximum number of equivalent adult red hake impinged and entrained in any year was 801 fish. Estimated numbers of equivalent adult winter flounder were higher, up to 4,401 fish in 1991. According to the authors, this total, representing less than 2 metric tons of biomass, was equivalent to 3 days of average catch by a typical class 2 trawler in the Gulf of Maine. It should be noted that these calculations are conservative because they assume that all of these equivalent adults would have been harvested. In reality, only a fraction would have been caught, with the remainder dying from natural mortality at ages older than 3 years. According to the National Marine Fisheries Service commercial fisheries database, more than 2000 metric tons of winter flounder were harvested by New England commercial fishermen in 1991. Thus, in spite of this conservative assumptions employed by Saila et al. (1997), the biomass of equivalent adult losses calculated by these authors is only about 0.1% of the New England harvest of winter flounder that occurred during 1991. Saila et al. (1997) also cited equivalent adult estimates developed for the Pilgrim Station on Cape Cod, showing that during the period from 1990-1995 entrainment losses at Pilgrim were larger (approximately 5,000-12,000) equivalent adults per year) than at Seabrook, but still small compared to commercial harvests.

Turnpenny (1988) found that equivalent adult losses of commercially harvested fish species at the Heysham 1, Hinkley B, Fawly, and Kingsnorth power stations in England and Wales for the year 1986 amounted to 0.5% or less of commercial landings in the designated International Council for the Exploration of the Sea (ICES) fishing areas offshore from these plants. This study did not include an assessment of entrainment impacts.

Turnpenny and Taylor (2000) summarized more than 20 years of data concerning impingement and entrainment of fishes at the Sizewell A and B Nuclear Power Stations on the Suffolk coast of East Anglia, U.K. They found that, expressed as equivalent adults, impingement and entrainment losses were equivalent to 0.54% of the recorded UK and international landings. Adult losses of only sole (1.5%) and herring (5.8%) exceeded one percent of the commercial landing figures. The authors noted that the equivalent adult methodology does not account for density-dependent factors that might tend to increase the survival, growth, and reproductive rates of individuals left in the population when some of their competitors are removed, thus, the values given should be regarded as overestimates.

Similarly, Greenwood (2008) estimated that impingement at the Longannet Power Station on the Forth Estuary, U.K. in 1999 and 2000 removed 90.9-152.5 metric tons of equivalent adult whiting, 13.2-49.5 tons of equivalent adult cod, and 9.8-37.2 metric tons of equivalent adult plaice from local populations. All of these values were small compared to commercial landings, discards and bycatch of these three species in the North Sea adjacent to the Forth Estuary. Greenwood (2008) was unable to estimate the fraction of local populations removed by impingement within the Forth Estuary, because of the inadequacy of available estimates of the total abundance of fish present in the estuary. Although impingement losses at Longannet Power Station were small compared to commercial harvests, Greenwood (2008) suggested that cumulative impacts of impingement at multiple power stations could be significant.

2.4 Studies of Cumulative Impacts of I&E

At least in principle, impacts of I&E on marine fish populations with coastwide distributions should be assessed on a cumulative basis, accounting for all water withdrawals that could affect each species. Newbold and Iovanna (2007) modeled the cumulative impacts of entrainment and impingement mortality at all U.S. coastal power plants on fifteen harvested marine fish populations. These authors utilized I&E loss estimates developed by USEPA (2002, 2004) to support the 316(b) Phase II rulemaking, together with harvest data obtained from the National Oceanic and Atmospheric Administration (NOAA) and life history information obtained from EPA and other sources. Density-dependent population models developed using this information were used to estimate the increase in population abundance that could occur if all entrainment and impingement were eliminated. According to the models, eliminating entrainment and impingement of California American shad, California anchovy, Atlantic cod, Atlantic herring, Atlantic mackerel, pollock, scup, silver hake, summer flounder, and winter flounder would increase the abundance of these species by less than 1%. Eliminating entrainment and impingement of Atlantic American shad and Atlantic menhaden would increase the abundance of these species by 1% - 3%. Eliminating entrainment and impingement of California striped bass, Atlantic striped bass, and Atlantic croaker would increase the abundance of these species by 20%-80%.

The explanation for the large impacts predicted for striped bass and Atlantic croaker is the comparatively high annual I&E mortality rates calculated for these species. The annual instantaneous mortality rate due to I&E of Atlantic striped bass (0.18) is substantially higher than the empirical estimates (0.068-0.13) obtained by Boreman and Goodyear (1988) for mortality to Hudson River striped bass due to entrainment at six Hudson River power plants. The annual I&E mortality rate for Atlantic croaker estimated by the authors (0.57) is higher than the target annual fishing mortality rates for many managed fish populations and is applied to the entire coastwide population, including components of the population that are not exposed to power plants. Populations of both Atlantic striped bass and Atlantic croaker have grown substantially since 1980 (Richards and Rago 1999, ASMFC 2005), and it does not appear plausible that the abundance of either species could be significantly increased by eliminating I&E.

Since I&E mortality rates in the model used by Newbold and Iovanna (2007) are estimated through model calibration, there is no simple way to determine the source of these very high values. However, it should be noted that the I&E loss rates estimated by EPA (2002, 2004) and used by Newbold and Iovanna (2007) were obtained by extrapolating I&E estimates from power plants with available data to plants with no available data based on relative intake flows. This procedure was acknowledged by the authors to have introduced potentially large and unknown uncertainties. Newbold and Iovanna (2007) characterized their analysis as a "screening" analysis and did not claim to have accurately estimated the impacts of I&E on any of the modeled populations.

Recognizing the potential importance of cumulative impacts of I&E, the Atlantic States Marine Fisheries Commission (ASMFC) established a "Power Plant Committee" to investigate the feasibility of coastwide assessments, using Atlantic menhaden as a test case. As reported by Heimbuch et al. (2007), the committee found that insufficient I&E data were available to perform a scientifically credible assessment, and concluded that it would not be scientifically defensible to extrapolate I&E estimates between power plants. The committee developed a model that could be used to link I&E mortality to the Atlantic menhaden stock assessment model used by the ASMFC, but could only demonstrate the use of the model with hypothetical I&E data.

2.5 Summary

Three published studies have addressed impacts of I&E on fish populations using retrospective analysis of historical data on impingement, entrainment, and population trends. In the updated Connecticut River study (Jacobson et al. 2004), the Barnthouse et al. (2003b) Salem assessment, and the Henderson et al. (1984) study of Fawley Power Station, the authors found no significant impacts due to I&E. Studies published in the Hudson River Monograph (Boreman and Goodyear 1988; Barnthouse and Van Winkle 1988) quantified impacts of I&E on individual year classes using empirical data, but did not extrapolate these impacts to long-term impacts on populations.

Seven studies (Jensen 1982; Jensen et al. 1982; Lorda 2000; Perry et al. 2003; Nisbet et al. 1996; Ehler et al. 2003, Heimbuch et al. 2007a) used a combination of population models and site-specific data to quantify potential impacts of I&E on populations. Three of these studies (Nisbet et al. 1996, Perry et al. 2003; Ehler et al. 2003) found potentially significant impacts on local fish populations, but only one of these three (Ehler et al. 2003) included empirical data showing an actual decline in abundance that could have been caused by I&E . Even this study is open to challenge due to the finding of White et al. (2010) that the assessment approach used by Ehler et al. (2003) significantly overstates entrainment impacts.

Four studies (Turnpenny 1988; Saila et al. 1997; Turnpenny and Taylor 2000; Greenwood 2008) compared I&E losses expressed as equivalent adults to commercial landings Although these studies do not directly address adverse impacts of I&E on fish populations, they provide evidence that any such impacts should be smaller than impacts caused by fishing.

Two studies addressed cumulative impacts of I&E at multiple power plants, however, one of these studies (Newbold and Iovanna 2007) was characterized by the authors as a screening study and the other (Heimbuch et al. 2007b) concluded that cumulative assessment is currently infeasible due to lack of I&E data for many facilities.

Section 3: Impacts of I&E on Food Webs

Rago (1984) noted that fish impinged or entrained at power plants are no longer available to serve as prey for predator populations. The reduction in available prey biomass includes both the biomass of the fish at the time it is impinged or entrained and the future growth that would have occurred before the fish was consumed by a predator. The loss of prey biomass could reduce the abundance and productivity of predator populations (Summers 1989). In addition to affecting predator abundance, losses of forage fish due to I&E could, at least in principle, lead to increases in the abundance of organisms such as zooplankton and phytoplankton that would otherwise have been consumed by the impinged or entrained fish. Super and Gordon (2003) argued that I&E disrupt the natural functioning of ecosystems by transferring energy down the food chain from higher predators to lower decomposers. Greenwood (2008) also suggested that such effects were possible, but cited no examples and provided no supporting information.

Regulation of food web dynamics is an example of an "ecosystem service" provided by marine and freshwater fish populations (Holmlund and Hammer 1999). Recycling of nutrients, regulation of ecosystem resilience, and redistribution of bottom substrates are other examples of ecosystem services provided by fish populations (Holmlund and Hammer 1999). Ecosystem services, as defined by Daily (1997), are "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life." The ecosystem services concept is now widely accepted as an organizing framework for linking ecosystem conditions and human well-being (Millennium Ecosystem Assessment 2005).

Restoration and preservation of services provided by aquatic and marine ecosystems was cited by EPA (2006) as a benefit of reducing I&E. If I&E were disrupting food webs or nutrient recycling, any such disruptions would be considered adverse environmental impacts, above and beyond any impacts on the specific species impinged or entrained. Documented cases of these types of disruptions have all involved the same causes discussed in later sections of this review: overfishing, pollution, habitat destruction, and invasive species. No published studies have identified impingement as being a contributing cause of food web disruption. However, one modeling study has addressed the potential for food web disruption due to entrainment (Summers 1989).

Summers (1989) used a food web model to investigate the potential indirect effects of entrainment of forage fish on striped bass, bluefish, and weakfish production in the Patuxent River, MD. He found that high levels of entrainment losses of preferred prey species (bay anchovy and Atlantic silversides) could cause significant reductions in predator production. However, the model developed by Summers (1989) suffers from two significant oversimplifications. First, it is structured as a conventional "trophic pyramid" in which forage fish feed only on zooplankton and benthic invertebrates and predators feed only on forage fish. Second, it assumes that entrained fish are removed from the food web and perform no ecological functions.

The idea that organisms within aquatic ecosystems may be grouped into relatively discrete "trophic levels" as primary producers (plants that fix carbon using sunlight as an energy source), primary consumers (animals that eat plants), secondary consumers (animals that eat primary consumers), and so on, at higher and higher levels was first formalized by Lindeman (1942). According to this theory, organisms at each level feed primarily on organisms at the next lower level. Animals that die before they are consumed are consumed by scavengers that feed primarily on dead organisms, or are degraded by decomposer organisms, primarily bacteria and fungi. Decomposition releases dissolved nutrients that can be used again by the primary producers at the bottom of the pyramid. As stated by Super and Gordon (2003), according to this view of food webs, entrainment short-circuits the trophic pyramid by killing small fish, which then return directly to the scavenger/decomposer pool rather than being consumed by predators. Predator consumption (and subsequent growth) is reduced in direct proportion to the losses caused by entrainment.

This characterization of ecosystems in terms of a "trophic pyramid" is now widely recognized by ecologists as a gross oversimplification. In a comprehensive review of terrestrial and aquatic food webs, Polis and Strong (1996) stated (p. 815) that "the notion that species clearly aggregate into discrete, homogeneous trophic levels is fiction." Rather than being organized into discrete levels, with plants at the base and large predators at the top, in real food webs most animals consume organisms from multiple trophic levels. Moreover, the food consumed by typical predator species is often derived from a combination of plant-based and decomposer-based production, and the species consumed change depending on developmental stage and spatial location. The characterization of ecosystem structure advocated by Polis and Strong (1996) is supported by a wide variety of theoretical and empirical food web studies such as Murdoch (1966), Peters (1977), Darnell (1961), Hanski (1987), Baird and Ulanowicz (1989), Hall and Rafielli (1991), Polis and Holt (1992), Vander Zanden and Vadeboncoeur (2002), and Thompson et al. (2007).

Food web structure in estuarine ecosystems is consistent with the view expressed by Polis and Strong (1996) that food webs are not organized into discrete trophic levels. Striped bass larvae, for example, feed primarily on copepods (Limburg et al. 1998), which are an important component of the zooplankton. Copepods, in turn, feed on both phytoplankton and on decomposer microorganisms growing on the surfaces of organic particles suspended in the water column. Juvenile striped bass feed on copepods, but also on larger invertebrates such as gammarids and chironomids (Gardinier and Hoff 1982). These invertebrates feed on plants and decomposing organic matter; in addition, gammarids are active predators on zooplankton and even fish eggs and larvae (Poje et al. 1988).

Striped bass begin feeding on fish when they reach a length of 76-150 mm, but still feed primarily on invertebrates until they reach a length of about 200 mm (Gardinier and Hoff 1982). Other estuarine fish species similarly feed on a wide variety of organisms at different stages of their life cycles. White perch feed primarily on invertebrates such as gammarids, but also on fish eggs and larvae and even plants (Bath and O'Connor 1985).

Juvenile bluefish prey primarily on smaller fish, but also consume blue crabs and sand shrimp (Juanes et al. 1993; Buckel and Conover 1997). The fish consumed by bluefish include other piscivore species (e.g., striped bass), planktivorous species (e.g., bay anchovy, American shad, and river herring), and benthic invertebrate-feeding species (e.g., white perch and Atlantic tomcod).

Rather than being removed from the food web, entrained forage fish remain within the web and are still available to support fish production. If not immediately consumed by predators, these fish are likely to sink toward the bottom and be consumed by benthic-feeding fish species, or by benthic invertebrates. These benthic species are themselves susceptible to predation, including predation by the same fish species that would have consumed the originally entrained forage fish. If, instead of being consumed, the entrained fish were decomposed by bacteria and fungi, these microorganisms would be susceptible to grazing by invertebrates such as Cladocera, copepods, or gammarids, which would in turn be available for consumption by small fish. Meanwhile, the phytoplankton and zooplankton that would have been consumed by the entrained forage fish would still be available for consumption by other forage fish.

Due to these complex biomass flow pathways, the impacts, if any, of entrainment on forage fish would be diffused throughout the entire ecosystem and would likely be much smaller than impacts predicted by models based on the conventional trophic pyramid concept. Since neither theoretical nor empirical studies have linked entrainment to disruptions in aquatic food webs, any suggestions that cooling water withdrawals have contributed to these disruptions are purely speculative.

The above conclusion does not necessarily apply to impingement. For power plants with fish return systems, impinged fish are returned to the source water body, so these conclusions should apply. However, for power plants without fish return systems, impinged biomass may be permanently removed from the source water body. As in the case of entrainment, no theoretical or empirical studies have linked these biomass removals to disruptions in aquatic food webs, however, it is possible to at least speculate that such effects could occur, if enough biomass were removed.

Section 4: Causes of Fish Population Declines Documented in "Blue Ribbon" Commission Reports

The status of fishery resources, especially marine resources, has been a matter of great national concern for many years. Over the past 20 years many committees have been convened and many reports have been written. This section discusses reports prepared by two especially prestigious organizations, the Pew Oceans Commission and the National Research Council.

4.1 Pew Oceans Commission

In 2003, the Pew Oceans Commission (2003), a blue-ribbon panel that was chaired by former Congressman, former Central Intelligence Agency Director and current Secretary of Defense Leon Panetta and included current NOAA Administrator Dr. Jane Lubchenco, evaluated scientific information and policy options for dealing with nine major threats to marine resources: nonpoint source pollution, point source pollution, invasive species, aquaculture, coastal development, overfishing, habitat alteration, bycatch, and climate change. Most of these same threats were also discussed in a report by the U.S. Commission on Ocean Policy (2004). Neither report mentions cooling water intake structures among the list of problems for which new regulatory policies are needed to protect and enhance marine resources.

The Pew Oceans Commission report was accompanied by supporting reports documenting adverse effects of overfishing, pollution, urban sprawl, invasive species, and aquaculture on marine ecosystems. The report on aquaculture (Goldburg et al. 2003) concluded that impacts of aquaculture facilities on marine ecosystems can be locally significant and they can be minimized through a variety of technologies and management practices. The other impacts addressed in the supporting reports are much more significant and difficult to control.

According to Dayton et al. (2002), worldwide, populations of large-bodied top carnivore species such as tuna, swordfish, salmon, and many sharks, have been drastically depleted by harvesting. As the populations of these species decline, fishermen shift their attention to smaller species, eventually depleting these populations as well. This process, termed "fishing down the food web," reduces the ability of predators to switch among prey species in response to natural fluctuations in abundance, gradually disrupting and truncating trophic relationships. This simplification of food webs can lead to unpredictable changes such as increased disease outbreaks and the proliferation of previously suppressed pests and weedy species. Dayton et al. (2002) also discuss the physical effects of collection gears such as bottom trawls and dredges, and the bycatch of unwanted fish captured and killed by fishermen who are targeting other species.

According to Boesch et al. (2003), nutrient enrichment is the most widespread pollution-related stress on coastal marine resources, affecting two-thirds of the surface area of estuaries and bays in the coterminous United States. Adverse effects of excess nutrients include oxygen depletion and reduced water clarity. Oxygen depletion prevents fish and other organisms from utilizing the affected areas, and reduced clarity reduces the growth of seagrasses and seaweeds that are important habitat for many fish species. Toxic contaminants such as heavy metals, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides have more localized distributions but have adversely affected marine resources in many bays and estuaries.

According to Beach (2003), counties bordering the Atlantic, Gulf of Mexico, and Pacific coasts contain 53% of the entire population of the U.S. In 2010, these coastal counties had an average population density of more than 300 persons per square mile, compared to an average density of about 60 persons per square mile for non-coastal counties. Increased densities of roads, parking lots, roofs, and other impervious surfaces increase surface runoff, leading to physical habitat degradation and nonpoint source pollution. Beach (2003) reported that clear correlations have been found between increased surface runoff and impaired biological resources, including fish populations. Since the populations of coastal regions of the U.S. are growing at a faster rate than populations of inland regions, adverse impacts of shoreline development can be expected to grow.

According to Carlton (2003), introduced species of crabs, mussels, clams, jellyfish, seagrasses, and marsh grasses now dominate marine ecosystems from the Hawaiian Islands to New England, and the rate of new introductions shows no sign of decline. In San Francisco Bay alone, one new species became established every 14 weeks between 1961 and 1995, and the Bay is now inhabited by more than 175 introduced marine invertebrates, fish, algae, and higher taxonomic plants. More than 100 introduced species inhabit Pearl Harbor. Recent invaders of Pacific coastal waters include the Japanese mahogany clam, European shore crab, Chinese mitten crab, Asian kelp, and Mediterranean green seaweed. Recent invaders of the Gulf of Mexico and Atlantic coasts include the brown mussel, Pacific spotted jellyfish, Asian whelk, and Asian shore crab. These invaders compete with or prey on native species, causing fundamental impacts on fisheries resources, human welfare, and ecosystem resources and services.

The Pew Oceans Commission report and supporting documents contain many policy recommendations intended to address all of the above impacts, but made no recommendations with respect to cooling water withdrawals at power plants or other industrial facilities.

4.2 National Research Council Reports

The U.S. National Research Council has published studies relevant to most of the causes of impacts discussed in the Pew Oceans Commission (2003) report. A National Research Council study (NRC 1995) identified five threats to the biodiversity of marine ecosystems, including overfishing, chemical pollution and eutrophication, physical habitat alteration, invasions of exotic species, and global climate change. The purpose of this study was to develop a research agenda for understanding the causes and consequences of changes in marine biodiversity.

Three studies addressed adverse impacts of overfishing. A 1998 study (NRC 1998) reviewed the adequacy of National Marine Fisheries Service (NMFS) stock assessments for five New England fish stocks (Gulf of Maine and Georges Bank cod, Georges Bank haddock, and Georges Bank and Southern New England yellowtail flounder). This review was motivated by concerns raised by the New England fishing industry that harvest restrictions imposed on these stocks were too severe and were not supported by sound fisheries science. The review found that NMFS' conclusions were adequately supported by the available information, that all five stocks were severely depressed due to overfishing, and that even more stringent measures might be required to promote recovery of the stocks.

A 1999 study (NRC 1999) addressed the long-term sustainability of marine fish harvesting. Like the Pew Oceans Commission (2003) report, this study documented a variety of adverse impacts of fishing on marine ecosystems, and recommended strategies for managing fisheries in a way that minimizes these impacts.

A 2006 study (NRC 2006) specifically addressed the validity of previously published research concerning ecosystem-level impacts of overfishing large marine predators and of harvesting fish from multiple trophic levels. The study concluded that available evidence supports the validity of this research, and recommended management approaches and research topics intended to promote sustainable harvests from multi-trophic level fisheries.

Two studies addressed impacts of invasive species. A 1996 study (NRC 1996) summarized information documenting the global transport of invasive species in ship ballast water, and discussed technologies and ballast management approaches for reducing this transport. A 2008 study (NRC 2008a) evaluated options for reducing the transport of invasive species into the Great Lakes through the St. Lawrence Seaway while at the same time enhancing the Great Lakes Region's role in global trade.

Two studies addressed inputs of nutrients and hazardous chemical pollutants to coastal marine waters. A 1993 study (NRC 1993) found that urban wastewater management practices were inadequate for protecting coastal marine resources. Nutrients, pathogens, and toxic organic pollutants were identified as high priority concerns. Metals, oils, and plastic debris were identified as medium-priority concerns. The study recommended an integrated strategy for combined management of point source and nonpoint source discharges, together with establishment of water and sediment quality standards that can be used to prioritize pollution control and environmental restoration needs. A 2009 study (NRC 2009) evaluated watershed management options necessary for reducing nutrient loadings to the Gulf of Mexico. Nutrient loading from the Mississippi River watershed has led to eutrophication of a large area of the Gulf of Mexico, with the result that a hypoxic "dead zone" develops during the summer months.

One study (NRC 2008b) addressed a habitat disturbance issue: marine debris. Ingested marine debris, particularly plastics, has been reported in necropsies of birds, turtles, marine mammals, fish, and squid. Besides physically interfering with the digestive systems of organisms, this material can absorb and concentrate toxic chemicals that are then delivered to the organism that ingests it. Additional hazardous marine debris includes abandoned fishing gear which can entangle and injure marine organisms.

No agency has ever asked the NRC to review impacts of power plant I&E on aquatic populations or ecosystems.

Section 5: EPA National Coastal Conditions Reports

The conclusions reached in the reviews discussed in Section 2 are largely supported by the U.S. Environmental Protection Agency (EPA)'s own review of coastal environmental conditions, contained in a series of National Coastal Conditions reports. The third and most recent of these reports, termed "NCCR III," was published in 2008 (USEPA 2008). This report which assesses the condition of all U.S. coastal waters, including Hawaii, south central Alaska, and the Great Lakes, is a collaborative effort involving EPA, NOAA, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, and other agencies representing states and tribes. It is intended to provide a snapshot of coastal conditions in 2001 and 2002. An update, including data collected through 2006, is expected to be published in 2011.

NCCR III, like the two earlier reports, uses five indices to evaluate the quality of coastal conditions: water quality, sediment quality, benthic community composition, coastal habitat condition, and fish tissue contamination. The water quality index is calculated from data on nitrogen and phosphorus concentrations, chlorophyll *a* concentration, water clarity, and dissolved oxygen concentration. All of these metrics are indicators of eutrophication resulting from excess nutrient inputs. The sediment quality index is calculated from data on contaminant concentrations and total organic carbon (TOC) concentrations in sediment. Contaminant concentrations are indicators of chemical pollution; TOC concentrations are indicators of pollution from untreated or partially treated sewage. The benthic community index is calculated from data on the species composition of benthic invertebrate communities. This metric is an indicator of the general health of benthic communities. The coastal habitat index is calculated from data on the rate of wetland habitat loss, and is an indicator of the impact of shoreline development on coastal ecosystem quality. The fish tissue contaminants index is calculated from data on concentrations of contaminants in fish tissue. This metric is an indicator of the extent of contamination of coastal food webs by bioaccumulative chemicals. In addition to the five coastal condition indices, NCCR III summarizes information on overharvesting of fish species in waters bordering the U.S. coastline.

On a scale of “poor” to “good,” NCCR III rated the overall condition of U.S. coastal waters as “fair.” With respect to the individual indices, NCCR III rated water quality as being “good to fair” and all other indices as being “fair,” “fair to poor,” or “poor.”

Chapter 9 of NCCR III provides a detailed evaluation of a particular site, Narragansett Bay, with respect to human uses and specific sources of environmental degradation. This is the only chapter that mentions electric power production. The impact of the thermal discharge from the Brayton Point station on the local winter flounder fishery is discussed, but impacts of cooling water withdrawals are not mentioned.

Section 6: Causes of Adverse Impacts Documented in Peer-Reviewed Literature

The peer-reviewed scientific literature documents large, even catastrophic changes in fish populations and communities resulting from eutrophication, invasive species introductions, and overfishing. Case studies documented in this literature are generally consistent with the conclusions of the Pew Oceans Commission (2003), the NRC reports, and the EPA Coastal Conditions reports and many of them were cited in one or more of those reports.

Excess inputs of nitrogen and phosphorus from pollutant discharges and surface runoff, have caused or contributed to major changes to fish communities in many freshwater and estuarine waterbodies (Carpenter et al. 1998). Excess nutrients stimulate blooms of nuisance algae and aquatic weeds. Senescence, death and decomposition of these plants cause oxygen depletion and fish kills. Some algal species release toxins that can cause mass mortalities of fish and shellfish. During the 1960s, the bottom waters Lake Erie were so severely affected by reduced oxygen levels that the lake was widely believed to be "dead or dying" (Kerr and Ryder 1997). In addition to causing oxygen depletion, eutrophication promotes shifts in aquatic food chains. Caddy (1993) noted that the fish community of the Great Lakes has shifted from dominance by benthic-feeding species such as sturgeon, bass, and perches to dominance by plankton-feeding species such as alewife, gizzard shad, and rainbow smelt. Similar shifts from benthic-based to plankton-based food chains have been observed in semi-enclosed marine water bodies such as the Baltic Sea, the Mediterranean Sea, and the Black Sea that have been affected by eutrophication (Caddy 1993).

Introductions of non-native species have also caused substantial harm to fish communities in many water bodies. According to Kerr and Ryder (1997), 139 non-native species have been introduced to the Great Lakes, and of these at least 13 have caused ecologically significant changes. Parasitism by sea lamprey that invaded the Great Lakes following the opening of the St. Lawrence Seaway caused the near-extinction of native lake trout. Alewife, another exotic, has displaced native species both through competition and through predation on early life stages of other fish (Madenjian et al. 2008). Recreational and commercial fisheries in the Great Lakes are now dominated by non-native salmonids, which were introduced to replace the depleted lake trout populations and control the non-native forage fish populations. The recent invasion of the Great Lakes by the zebra mussel *Dresseina polymorpha* has caused additional changes due to the ability of these organisms to efficiently filter phytoplankton and suspended organic matter from the water column, depleting the waterbody of resources important for native species of larval fishes and other aquatic life (Mills et al. 2003). Round goby *Neogobius melanostomus*, originally found in the Great Lakes in 1990, is now common in all of the Lakes and dominates the near-shore habitat of parts of Lakes Erie and Ontario, displacing native species (Jude 1997). Round goby are also now one of the top 5 species of larvae entrained by power plants on the Great Lakes (EPRI 2011) indicating the ability of a species to significantly increase in abundance despite the presence of entrainment losses.

Invasions of non-native species have also greatly altered biological communities in the San Francisco Bay area. The invasion of the Asian clam *Potamocorbula amurensis* is especially well documented (Nichols et al. 1990, Carlton et al. 1990). From a small local population established in Suisun Bay in 1986, this clam spread throughout the bay area within two years and became the dominant benthic filter-feeder in Suisun Bay and San Pablo Bay. As noted by Carlton et al. (1990), *P. amurensis* is only one of many species that have been deliberately or accidentally introduced to the bay, many in ballast water discharged by trans-oceanic shipping vessels.

On a global scale, many scientists now believe that overharvesting may be the greatest cause of harm to the structure and function of marine fish communities. Myers and Worm (2003) recently found that harvesting has reduced the worldwide biomass of large, predatory fish by 90% from the levels that were present prior to the introduction of modern fishing technologies. These predators play an important role both in controlling the abundance of other species and in controlling the pathways through which energy and biomass move through marine food webs (Steele and Schumacher 2000, Jackson et al. 2001, Daskalov 2002). Reducing the abundance of large predators leads to increased abundance of forage fish and pelagic invertebrates (e.g., jellyfish), decreased abundance of zooplankton, and increased abundance of phytoplankton and suspended organic matter (Steele and Schumacher 2000). Many of these changes are similar to, and nearly indistinguishable from, changes in food web structure caused by eutrophication (Jackson et al. 2001, Daskalov 2002). Overharvesting of demersal (bottom-dwelling) predators such as cod, haddock, and yellow flounder in the North Atlantic during the 1980s led to replacement of these species by small sharks and skates (Fogarty and Murawski 1998). Subsequent overharvesting of sharks and skates apparently has led to an increase in the abundance of pelagic species such as herring and mackerel, which are important prey species for demersal predators such as cod and spiny dogfish.

The changes observed in the fish communities present in lakes and coastal water bodies are often a result of a combination of stressors. For example, Lotze and Milewski (2004) have documented the profound effects of nutrient loading, harvesting, and habitat change on the fish communities of the Quoddy Region, Bay of Fundy since the arrival of the first European colonists. Mills et al. (2003) documented causes of changes in the Lake Ontario food web that occurred over the period 1970-2000. These authors found that reductions in phosphorus loading, stocking of salmonids, sea lamprey control, harvesting, predation by cormorants, climate change, and the zebra mussel invasion have interacted to produce major changes in the fish community.

Section 7: Causes of Adverse Changes in Specific Fish Populations

This section summarizes current understanding concerning causes of declines in the abundance of specific fish populations. Most of the information comes from stock assessments performed by NMFS, regional fisheries commissions, and other resource management agencies, however, in some cases these agency-driven assessments are supported by peer-reviewed literature. The emphasis on marine fish populations reflects the fact that the Magnuson-Stevens Fishery Conservation and Management Act of 1976 (MSA) requires agencies to assess the status of these populations. Information on freshwater fish populations, including most Great Lakes fish populations, is less complete but is discussed where data are available. This section summarizes the status of harvested fish species that have been identified as being susceptible to E&I (EPRI 2011), and for which recent information on stock status is available.

7.1 Atlantic Striped Bass *(Morone saxatilis)*

Striped bass was the first and most intensively studied fish species for which concerns about adverse impacts of I&E were raised (Barnthouse et al. 1984). The research program initiated to address potential impacts on the Hudson River striped bass population is still one of the most comprehensive fisheries-related environmental assessment studies that has ever been performed (Barnthouse et al. 1988). Concurrently, investigations into the causes of the catastrophic decline in abundance of Chesapeake Bay striped bass (Richards and Rago 1999) led to recognition of overfishing as the principal cause of the decline and to major changes in management approaches for striped bass and other Atlantic coastal fish populations. The rapid increase in abundance of the Chesapeake, Delaware, and Hudson River striped bass populations that occurred following the three-year moratorium on striped bass harvests that was instituted in 1986 was widely reported in the popular press and is fully documented in stock assessment reports published by the Atlantic States Marine Fisheries Commission (ASMFC). However, recent declines in abundance of adult striped bass, in particular a decline in the abundance of large striped bass in northern New England, have raised concerns about the health of the Chesapeake Bay population, which is the primary source of these fish. Poor water quality and increased disease incidence are suspected as contributing causes. In response to these concerns, the ASMFC has initiated the development of an addendum to the Interstate Striped Bass Management Plan that would reduce harvesting and promote population growth (ASMFC News Release, March 24, 2011).

7.2 American Shad *(Alosa sapidissima)*

American shad is an anadromous fish species native to the U.S. Atlantic coast. Most rivers along the Atlantic coast historically supported distinct American shad populations, and this species has been harvested by fishermen since colonial times (Limburg et al. 2003). Shad landings peaked at nearly 25,000 metric tons in 1896, but have since declined to a very small fraction of that value. Fisheries, dams, and pollution of spawning and rearing habitat have all contributed to these declines (Limburg et al. 2003). Since 1985, the abundance of several of the most important American shad spawning stocks, including the Connecticut River and Hudson River stocks, have continued to decline in spite of improvements in water quality and actions taken to remove barriers to upstream migration. A stock assessment performed by the ASMFC (2007) concluded that the mortality rate of this species had increased to an unsustainable level, but was unable to conclusively identify the cause of the increase. The two hypotheses being actively considered are (1) incidental catches in fisheries directed at other species and (2) predation by striped bass.

7.3 River Herring *(Alosa pseudoharengus* and *A. aestivalis)*

Alewife and blueback herring, collectively termed "river herring," are closely related to American shad. Like American shad, river herring are anadromous and have in the past been adversely affected by dams, pollution, and overfishing. Also like American shad, the abundance of spawning stocks in many East Coast rivers has declined to very low levels in recent years (ASMFC 2009). Because of lack of data, it has not been possible to identify the cause(s) of the decline in river herring abundance. Savoy and Crecco (2004) concluded that predation by striped bass is the most strongly supported explanation for the decline in abundance of both river herring and American shad in the Connecticut River. Similarly, Heimbuch (2008) found that the increase in prey consumption by the Hudson River's growing striped bass population is sufficient to explain the observed decline in abundance of juvenile river herring in the Hudson. However, overfishing and bycatch of river herring in fisheries targeting other species may also be contributors.

7.4 Winter Flounder *(Pseudopleuronectes americanus)*

Winter flounder spawn in inshore waters, including bays, coastal salt ponds, and tidal rivers from the Middle Atlantic States to Newfoundland. Larvae and juveniles are found in these same habitats. Adult winter flounder are found inshore during winter and spring, but move offshore to deeper, cooler water during summer. They are on of the top five species of fish impinged at power plants in the Northeastern Region (EPRI 2011). For management purposes, the National Marine Fisheries Service recognizes three distinct stocks of winter flounder: a Georges Bank (GB) stock, a Gulf of Maine (GOM) stock, and a Southern New England-Mid Atlantic (SNEMA) stock. Abundances and harvests of all three stocks have greatly declined since 1980. The NMFS Northeast Fisheries Science Center most recently completed assessments of the status of all three stocks in 2008 (NEFSC 2008). The GB and GOM winter flounder assessments concluded that these stocks are being overfished. The SNEMA stock was found to be severely depleted, with fishing mortality still far above a sustainable level.

7.5 Weakfish *(Cynoscion regalis)*

Weakfish spawn offshore near the mouths of estuaries and coastal rivers from Florida to New England. They are one of the top 5 species of fish impinged at power plants in the Northeastern Coastal Region (EPRI 2011). For management purposes, all weakfish are considered to be part of a single coastwide stock. The NMFS Northeast Fisheries Science Center completed an updated stock assessment in 2009 (NEFSC 2009). This assessment concluded that the abundance of weakfish declined by approximately 80% from 1999 to 2008. Several hypotheses that could explain this decline were investigated using statistical models and supporting empirical evidence. Overfishing was ruled out as a contributor, because fishing mortality rates on weakfish have been stable or declining in recent years. The decline in stock productivity was also deemed too large to be accounted for by unreported landings and discards. Rising sea surface temperatures were eliminated as a potential cause, because water temperature shifts were not significantly linked to increased juvenile weakfish mortality. Disease, toxins, and parasitism were also investigated, but no evidence linking these stressors to weakfish production was found. The assessment identified enhanced predation by striped bass and spiny dogfish, especially on age 0 weakfish as the most likely cause, although statistical correlations are the only evidence supporting this conclusion. The weakfish stock has been classified as "depleted" by the ASMFC, even though it is not considered to be overfished.

7.6 Red Drum *(Sciaenops ocellatus)*

The red drum is found in estuarine and nearshore coastal waters of the Gulf of Mexico and the eastern seaboard. The species is most abundant along the Gulf of Mexico and South Atlantic coasts. Spawning peaks in September and October, in nearshore waters, in the vicinity of passes (gaps between barrier islands), and in estuaries (Murphy and Taylor 1990). The South Atlantic red drum stock consists of two substocks: a northern region substock, found in coastal waters from North Carolina northward to New Jersey, and a southern region substock found from South Carolina to southern Florida. The most recent stock assessment for Atlantic red drum was completed in 2009 (South Atlantic Fishery Management Council 2009). The coastal red drum population was severely depleted by overfishing during the 1980s, and since that time commercial harvesting has been greatly restricted. At present, harvesting is permitted only within length windows that vary slightly between regions and states (e.g., 18 to 27 inches total length from North Carolina northward, 14 to 27 inches total length from South Carolina southward). According to the most recent assessment, Atlantic red drum is no longer being overfished, and the abundances of both the northern region and southern region substocks are increasing.

The last available stock assessment for Gulf of Mexico red drum was completed in 1999 (Porch 2000). According to this assessment, the abundance of Gulf of Mexico red drum declined greatly from the 1970s through the 1990s. Although harvest restrictions had been imposed, significant recovery of the population had not occurred.

7.7 Atlantic Menhaden *(Brevoortia tyrannus)*/Gulf Menhaden *(B. patronus)*

Atlantic menhaden and gulf menhaden are closely related species that are among the most abundant and commercially important marine fish species in North America. Atlantic menhaden is common along the Atlantic coast from the northern Gulf of Maine to central Florida. Gulf menhaden is common along the Gulf of Mexico coast from Louisiana to southeastern Florida. Adult menhaden occur primarily in large schools, and undergo seasonal migrations along the coast. At the northern end of the range of Atlantic menhaden some spawning occurs in estuaries and bays, but throughout most of the range of both species spawning occurs at sea. After hatching, larvae are transported to estuarine nursery areas by onshore and along-shore currents. Most menhaden enter estuaries as juveniles and remain there throughout the growing season. Most commercial harvesting of menhaden occurs at sea, although active bait fisheries exist in major estuaries such as Chesapeake Bay. They are the most common fish impinged at power plants in the Northeastern Coastal Region (EPRI 2011).

The most recent stock assessment for Atlantic menhaden (ASMFC 2011) concluded that fishing mortality on this population has reached the overfishing threshold. Moreover, the number of young menhaden entering the population has been declining. The ASMFC has initiated the development of an addendum to the Interstate Fisheries Management Plan for Atlantic menhaden that would promote their increased abundance and reproduction. An increase is desired not only to promote the sustainability of the Atlantic menhaden stock, but also to provide adequate prey for predators such as bluefish, striped bass, and weakfish.

The most recent stock assessment for Gulf menhaden concluded that this species is fully exploited but relatively stable.

7.8 Atlantic Croaker *(Micropogonias undulatus)*

The Atlantic croaker occurs in estuarine and nearshore coastal waters between Mexico and Massachusetts. Spawning occurs along the continental shelf, with larvae and early juveniles being transported to estuarine nursery areas by onshore and along-shore currents. Both juveniles and adults are abundant in estuaries and nearshore waters. They are one of the top five species of fish impinged at power plants in the Mid-Atlantic Coastal Region (EPRI 2011). Atlantic croaker is harvested in mixed-stock fisheries, using a variety of gears. The most recent stock assessment (ASMFC 2010) concluded that fishing mortality for this species is relatively low and that the abundance of the coastal stock has been increasing since the 1980s.

7.9 Pacific Rockfishes *(Scorpaenidae)*

More than 90 species of groundfish (fish that live on or near the bottom) are managed by the Pacific Fisheries Management Council. Of these, more than 60 species are "rockfishes" belonging to the family *Scorpaenidae*. Rockfishes typically have low natural mortality, high longevity, and low rates of reproduction. These life history characteristics make them susceptible to overfishing. According to the Pacific Fisheries Management Council (2008), many rockfish stocks were severely depleted by overfishing between 1950 and 1990.

The 2008 Pacific coast groundfish stock assessment (PFMC 2008) listed 7 rockfish stocks as being depleted: bocaccio (*Sebastes paucispinis*), canary rockfish (*S. pinniger*), cowcod (*S. levis*), darkblotched rockfish (*S. crameri*), Pacific ocean perch (*S. alutus*), widow rockfish (*S. entomelas*), and yelloweye rockfish (*S. ruberrimus*). Abundances of all 7 species were reduced below the depletion threshold defined by the Council between 1990 and 1995. As required by the Magnuson-Stevens Fishery Conservation and Management Act, rebuilding plans for all species were developed and harvests were restricted. According to the 2008 assessment, fishing mortality rates on all species are now below the target fishing mortality rates specified by the Council Spawning stock sizes of all species except the cowcod are now growing at rates consistent with their rebuilding plans.

7.10 Lake Whitefish *(Coregonus clupeaformis)*

The lake whitefish has historically been one of the most valued commercial fish species in the Great Lakes. Whitefish abundance and harvests in all five Great Lakes began to decline in the 1940s, and reached all-time lows in the 1960s and early 1970s. Although overfishing is believed to have been a major cause of decline, other factors were also important. Sea lamprey predation, competition and predation by introduced planktivores (e.g., alewife, rainbow smelt, and white perch), and nutrient enrichment were also contributing causes (Nalepa et al. 2005). Measures taken to address these stressors included harvest restrictions, lamprey control, introduction of salmonids to suppress planktivore populations, and control of phosphorus inputs. As a result of these multiple management actions, whitefish populations in all five lakes recovered by 1990 (Nalepa et al. 2005).

A new threat to lake whitefish populations, however, has appeared. The zebra mussel (*Dresseina polymorpha*) was first discovered in Lake St. Clair in 1988 and soon spread to all of the Great Lakes. The spread of zebra mussels is believed to be linked to a decline in the abundance of the benthic invertebrate *Diporeia*, a major food source for whitefish (Nalepa et al. 2005). A decline in *Diporeia* abundance beginning in the 1990s was closely followed by declines in the growth rates, condition factors, and abundance of whitefish, especially in Lake Michigan and Lake Ontario. These declines are not uniform, and vary both between lakes and between basins within lakes. In addition to declines in abundance, changes in the spatial distribution of whitefish have occurred in Lakes Michigan, Huron, and Ontario. Hypotheses proposed to explain these changes include increased surface-water temperatures associated with climate change, increased light penetration due to phytoplankton filtration by zebra mussels, and the loss of *Diporeia* (Nalepa et al. 2005).

Section 8: Summary

The diverse literature discussed in this report, including studies of both marine and freshwater ecosystems throughout North America, consistently identifies overfishing, habitat destruction, pollution, and invasive species as being the predominant causes of past and present impairment of fish populations and the ecosystems that support them. In those few cases where impacts of I&E have been specifically investigated, such impacts have rarely been found. Some model-based studies (Nisbet et al. 1996; Perry et al. 2003) have suggested that potentially significant impacts might occur, but in only one study, of clinid kelpfish entrained at the Diablo Canyon Power Plant (Ehler et al., 2003), have authors cited empirical data to support a conclusion that a significant impact of I&E on a local population may be occurring. Even in this case other authors (White et al. 2010) have found that the method used to reach this conclusion is flawed and overstates impacts.

It is difficult to compare I&E to most of the stressors addressed in this report. I&E do not physically alter the ability of habitat to support fish, either because of physical or chemical alteration. I&E is comparable to fishing, however, in that both processes act through removal of fish from populations. Although I&E generally remove fish at an earlier age than does fishing, impacts of both can be expressed in terms of annual mortality rates, which then can be compared. For example, Barnthouse et al. (2003b) estimated that impingement and entrainment of weakfish at the Salem Nuclear Generating Station was equivalent, in terms of impact on the coastal weakfish population, to raising the rate of fishing mortality from the ASMFC-approved target fishing rate of 0.5 to 0.517, a change too small to be detected using typical fisheries data and assessment methods.

A simple example serves to illustrate why fishing is such a powerful influence on fish populations, as compared to I&E. Boreman and Goodyear (1988) estimated that entrainment mortality of striped bass due to all Hudson River power plants in 1974 and 1975 to range from 0.068 to 0.13, equivalent to reducing the sizes of the 1974 and 1975 year classes by 6.8% to 13%. No estimates of fishing mortality for striped bass during this period are available, however, the current target fishing mortality rate established by the ASMFC is 0.3 (ASMFC 2003). The cumulative impact of harvesting a year class of fish over many years is far larger than the impact of a single year of mortality due to I&E. Hudson River striped bass are susceptible to entrainment for only a few months, and to impingement primarily during their first year of life. In contrast, once they have entered the fishery, they remain susceptible to fishermen for the remainder of their lifespan that is typically 12 to 15 years and may be as long as 30 years. This mortality, which is believed by the ASMFC to be sustainable, is equivalent to an exploitation rate of 0.24, i.e., removing 24% of the entire population every year.

It is often said that it is impossible to prove a negative. Although adverse impacts due to I&E have not been conclusively documented in published studies, this absence does not prove that adverse impacts are not occurring or could never occur. However, the limited documentation of such impacts, after 40 years of operation of large power plants, some of which have been conducting extensive monitoring programs for several decades, provides substantial evidence that any such impacts are small compared to impacts identified by the Pew Oceans Commission (2003) and other sources as being major threats. Most importantly, there is no peer-reviewed scientific evidence to support a conclusion that reducing I&E via regulation of cooling water intakes will result in measurable improvements in recreational or commercial fish populations or ecological services.

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Program:

Fish Protection at Steam Electric Power Plants

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