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Review

Impacts of entrainment and impingement on fish populations: A review of the scientific evidence

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ARTICLE INFO

Article history:
Received 1 November 2012
Received in revised form
28 February 2013
Accepted 1 March 2013
Published on line 20 April 2013

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

ABSTRACT

In 1972, the United States Congress enacted §316(b) the Clean Water Act, which mandates minimization of the adverse impacts of entrainment and impingement of fish and other aquatic life at cooling water intake structures. Since the Act was passed, there has been continuous controversy over the magnitude of any such impacts and over the need for mitigating measures to reduce these impacts. The objective of this paper is to examine the published scientific information relevant to this issue The review includes (1) peer-reviewed literature reporting results of studies of impacts of entrainment and impingement at power plants on fish populations, (2) peer-reviewed literature and "blue-ribbon" commission reports on aquatic resource degradation that evaluate causes of observed degradation of aquatic ecosystems, and (3) EPA's own assessments of causes of degradation in coastal environments. The clear conclusion from the review is that any impacts caused by impingement and entrainment are small compared to other impacts on fish populations and communities, including overfishing, habitat destruction, pollution, and invasive species. The available scientific evidence does not support a conclusion that reducing entrainment and impingement mortality via regulation of cooling water intakes will result in measurable improvements in recreational or commercial fish populations.

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. 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* [emphasis added]." The adverse impacts that were the subject of the amendment result from (1) the drawing of fish and shellfish eggs and larvae into and through the condenser cooling systems of power plants, where mechanical and thermal stresses can cause high levels of mortality, and (2) trapping of fish against the screens that prevent debris from being drawn into the cooling water intake. These processes are referred to, respectively, as "entrainment" and "impingement." In 1976, EPA issued a rule implementing §316(b); however, that rule was suspended on procedural grounds in 1977. For more than 20 years beginning in 1977, no rule was in place and permitting authorities made decisions implementing §316(b) on a case-by-case, site-specific basis. As a result of a lawsuit initiated by environmental groups, EPA agreed in 1995 to issue regulations implementing §316(b) in 1999. This deadline was later extended, and the rulemaking was subdivided into three phases. Phase I would cover new cooling

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1462-9011/$ – see front matter
http://dx.doi.org/10.1016/j.envsci.2013.03.001

water intake structures, Phase II would cover existing intake structures withdrawing more than 50 million gallons of cooling water per day, and Phase III would cover existing intake structures withdrawing between 2 and 50 million gallons per day. EPA issued the final Phase I rule in 2001 [FR 66(243):65255-65345]. EPA issued a final Phase II rule in 2004 [FR 69 (131):41575-41693]. This rule was suspended in 2007 after several key provisions were overturned by the U. S. 2nd Circuit Court of Appeals. EPA issued a final Phase III rule in 2006 [FR 71(116):35006-35046]. In 2011, EPA proposed a new rule that would be applicable to both Phase II and Phase III facilities [FR 76 (76):22174-22288].

All of these rules continue to be controversial because of the perception that valued aquatic resources are at risk, and because the costs of compliance, especially for existing facilities, can be extremely high. Interestingly, §316(b) does not define the term ''adverse environmental impact.'' Throughout the 1970s, the term was understood by most scientists involved in environmental impact studies to refer to adverse changes in the abundance or productivity of populations of fish or shellfish susceptible to entrainment and impingement. Intensive field and laboratory investigations were conducted to address impacts of entrainment and impingement on fish populations in several major ecosystems, most notably the Connecticut River (Merriman and Thorpe, 1976) and the Hudson River (Barnthouse et al., 1988a).

Since 2001, EPA and many state agencies to whom authority to implement §316(b) has been delegated have issued rules in which adverse impacts have been implicitly or explicitly defined as entrainment and impingement per se, irrespective of whether any adverse changes in populations can be demonstrated or predicted.

EPA asserted in the preamble to its 2004 Phase II rule that ''multiple types of undesirable and unacceptable impacts may be associated with Phase II existing facilities, depending on conditions at the individual site.'' The preamble cited a wide variety of potential adverse impacts on populations and ecosystems that could potentially result from entrainment and impingement. EPA used data obtained from power plant operators and other sources to estimate that annual mortality of fish and shellfish due to entrainment and impingement at large power plants was equivalent to a loss of 3.4 billion one-year-old organisms. However, the literature cited to document the occurrence of potential population and ecosystem-level effects resulting from these losses included only two peer-reviewed scientific paper (Boreman and Goodyear, 1988; Summers, 1989), neither of which involved measurements of actual population or ecosystem changes.

Yet, during the 40-year period over which rules have been developed, challenged, and revised, power plants with once-through cooling have been operating continuously throughout the U.S. and Europe, many with extensive monitoring programs. At the same time, scientists and resource management agencies concerned about degradation of freshwater and marine resources have conducted many studies intended to identify causes of observed population and ecosystem decline.

The purpose of this paper is to evaluate the scientific validity of arguments concerning adverse impacts of entrainment and impingement through a review of the peer-reviewed scientific literature on fish population depletion and on ecosystem services. The review includes (1) peer-reviewed literature reporting results of studies of impacts of entrainment and impingement at power plants on fish populations, (2) peer-reviewed literature and ''blue-ribbon'' commission reports on aquatic resource degradation that evaluate causes of observed degradation of aquatic ecosystems, and (3) EPA's own assessments of causes of degradation in coastal environments. There is extensive literature on impingement and entrainment, most prepared by or for power companies as part of regulatory compliance activities. Similar studies have also been performed by non-governmental environmental organizations (NGOs). This ''gray'' literature has rarely been independently peer-reviewed, is highly variable in quality, and is inevitably vulnerable to charges of lack of objectivity. For these reasons, this review is limited to literature that has been independently and professionally peer reviewed.

The issue is not whether entrainment and impingement could *potentially* have adverse environmental impacts, but on whether any such impacts have been shown to occur over the 40 years since the enactment of §316(b), either through direct study of power plant impacts or through studies identifying causes of observed population and ecosystem degradation.

2. Peer-reviewed studies of adverse impacts of entrainment and impingement

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 entrainment and impingement 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 entrainment and impingement 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 in1976 (Merriman and Thorpe, 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 entrainment and impingement 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